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Principles of Power Electronics

Dr. Rajiv Singh
Neeraj Kaushik, Harsh Shrivastava

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CHAPTER 1

CONCEPT OF POWER ELECTRONICS

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ABSTRACT:

Electrical engineering's field of power electronics deals with the processing of high voltages and currents to provide power for a range of purposes. These domains all require stable and dependable electric power with the desired requirements, from domestic electronics to equipment in space applications. Power supply is transformed from one form to another, supplying regulated and controlled power, employing power semiconductor switches and control mechanisms. In this chapter we discuss about power electronic, application of power electronics system in daily life, types of power electronics convertors, merits and demerits of power electronics convertors.

KEYWORDS:

Electric Power, Power Electronics, Power Semiconductor, Power Quality, Power Module, Voltage Control.

INTRODUCTION

The description of power electronics is given, along with some of its essential attributes, such as high efficiency and dependability[1]. We introduce certain analysis techniques, such as energy balance and switch matrix analysis. Examples of energy balances for dc-dc power converters are provided. The difficulties of designing and running switching circuits are discussed, along with the implications of Kirchhoff's equations for the functioning of switching power converters. Presentations are made on classes of idealised power semiconductor devices and switching devices. There are defined switching operations and control options such as duty ratio control, pulse-width modulation, and phase control. Examples of uses and trends are explored in the areas of power sources, transportation, computer power, and renewable energy.

The need for electric power in various forms has been spurred by the growing emphasis on electrification for a cleaner environment. Electrical engineering's field of power electronics deals with the processing of high voltages and currents to provide power for a range of purposes. These domains all require stable and dependable electric power with the desired requirements, from domestic electronics to equipment in space applications. Power supply is transformed from one form to another, supplying regulated and controlled power, employing power semiconductor switches and control mechanisms. Motor control is advancing as transportation systems become more electrified, whilst switched-mode power supplies are a typical application of power electronics where power density, dependability, and efficiency are of utmost importance.As a result, the study of power electronics is multidisciplinary and involves components including control systems, electromagnetic devices, electrical motors, mechanical actuators, and semiconductor physics [2]–[4].

Power generated must be handled in order to meet the grid's requirements for AC voltage, particularly in the case of renewable energy[5]. For instance, a solar cell produces direct current (DC) energy, the output power of which depends on the operating voltage and incident sun irradiation. It is crucial to take full advantage of the electricity that the cell has to offer at its output and to transfer it to the grid as efficiently as feasible. In order to operate the solar cell at its peak power point, the interface that links the solar cell to the grid should produce AC power that is compatible with grid specifications.In order to reduce power generation losses, the conversion of this DC power to AC power also needs to be done more effectively. Power semiconductor devices with sophisticated control systems that track output and input parameters and manage switches make this possible.

Modern power semiconductor devices, including silicon carbide, gallium nitride field effect transistors (FETs), and power diodes, are the result of advancements in older ones[6]. The broad band gap of these devices enables high voltage operation, efficient thermal control, and exceptional features. As a result, lossy linear power supply and voltage regulators have been replaced by power electronics, even in noise-sensitive sectors. When compared to silicon devices, the fundamental benefit of these devices is that they can sustain high voltage. In order to deliver the same amount of power, the systems might be built with high-voltage capabilities, which reduce current consumption and boost efficiency. Additionally, running the devices at greater switching frequencies results in smaller passive components, which helps to make the systems more compact. Thermal designs are made simpler by being able to endure higher temperatures.

Power electronic systems are used in a variety of applications, such as:

1. Power Generation
2. Power Transmission
3. Power Distribution
4. Power Control

Power semiconductor devices are used in all of these applications to switch the input voltages and currents to produce the necessary outputs. To handle high voltages and currents, the basic semiconductor devices diodes, FETs, and bipolar junction transistors (BJTs) have different constructions. So, we have silicon-controlled thyristors (SCRs), power diodes, power MOSFETs, power BJTs, insulated gate bipolar transistors (IGBTs), gate turn-off thyristors (GTOs), and so forth. The power levels, switching frequency needs, efficiency, and kind of inputs and outputs are taken into consideration while choosing a device. For instance, the power handled by an EV powertrain is on the order of kW.Power MOSFETs, which can resist high voltages and switch at higher frequencies, are frequently employed in these applications. Silicon-controlled rectifiers (SCRs) are employed in power transmission, where the handled power is on the order of a few megawatts. Block diagram of typical power electronics system is illustrate below in Figure 1.

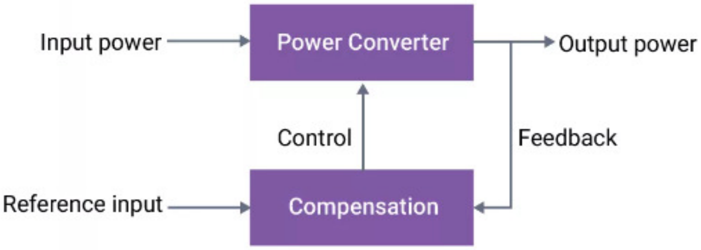

Figure 1: Block Diagram of typical power electronics system.

LITERATURE REVIEW

J. Afonso et al.[7] reviewed on power electronics technologies for power quality improvement. Nowadays, new challenges arise relating to the compensation of power quality problems, where the introduction of innovative solutions based on power electronics is of paramount importance. The evolution from conventional electrical power grids to smart grids requires the use of a large number of power electronics converters, indispensable for the integration of key technologies, such as renewable energies, electric mobility and energy storage systems, which adds importance to power quality issues. Addressing these topics, this paper presents an extensive review on power electronics technologies applied to power quality improvement, highlighting, and explaining the main phenomena associated with the occurrence of power quality problems in smart grids, their cause and effects for different activity sectors, and the main power electronics topologies for each technological solution. More specifically, the paper presents a review and classification of the main power quality problems and the respective context with the standards, a review of power quality problems related to the power production from renewables, the contextualization with solid-state transformers, electric mobility and electrical railway systems, a review of power electronics solutions to compensate the main power quality problems, as well as power electronics solutions to guarantee high levels of power quality. Relevant experimental results and exemplificative developed power electronics prototypes are also presented throughout the paper [8]–[10].

H. Wang et al.[11] Proposed power electronics reliability. This article aims to provide an update of the reliability aspects of research on power electronic components and hardware systems. It introduces the latest advances in the understanding of failure mechanisms, testing methods, accumulated damage modelling, and mission-profile-based reliability prediction. Component-level examples (e.g., Si IGBT modules, Sic MOSFETs, GaN devices, capacitors, and magnetic components) are used for illustration purposes in addition to system-level studies. The limitations and associated open questions are discussed to identify future research opportunities in power electronics reliability.

S. Buttner et al reviewed on profitability on low temperature power electronics and potential applications. This article presents an investigation of the profitability of cryogenic power electronics at different cooling and ambient temperatures. Thermodynamic fundamentals of low-temperature refrigeration processes are considered and the Carnot efficiencies of state-of-the-art refrigerators are evaluated in order to establish the necessary power loss reduction for energetic profitability of low-temperature to cryogenic power electronic systems down to 77 K. In this context, special attention is paid to two loss contributions in a power electronic system which, based on investigations on active and passive components, show the greatest potential for loss reduction at low temperatures. These are the on-state losses of Si and GaN transistors and the DC winding losses of inductors. The analysis shows that over the entire low temperature range, the loss reduction in a cryogenic converter can hardly compensate for the electrical power required to provide the necessary cooling capacity when cooling against an ambient temperature of 300 K.

A. Hasim et al. reviewed on power electronics for nearshore wave energy converter applications. In compliance with the green energy policy, mitigation from high fossil fuel dependency is becoming a new objective for most countries, including Malaysia. Wave energy is among extensively explored renewable energy relatively clean, sustainable, and inexhaustible resources. To this day, neither definite wave energy technology nor widely available commercial wave farm supplying the grid has existed. Therefore, wave energy harvesting is the most compelling solution, especially in regions where the possibility of grid connection is low in the nearest future. Like other renewable energy, the voltage amplitude and frequency generated from waves are unstable and may vary continuously. This uncertainty has created energy transfer challenges since the grid requires a stable and uninterrupted energy supply. Therefore, power electronics devices are employed to modulate the controller circuits' pulse width. Further understanding of the relationship between wave energy conversion technology and its power conversion, particularly for nearshore applications, is summarized. This work also discussed selected wave energy conversion research and power conversion system implemented and studied in Malaysia. Finally, this review can provide extensive overview and broad understanding into power conversion system for Wave Energy Conversion, especially for nearshore applications.

D. Van Nijen et al. Explored the benefits, challenges, and feasibility of integrating power electronics into c-Si solar cells. Power electronics traditionally plays a crucial role in conditioning the power of photovoltaic (PV) modules and connecting the systems to the electricity grid. Recently, PV module designs with more sub-module power electronics are gaining increased attention. These designs can offer higher reliability and improved resilience against non-uniform illumination. In this review, we explore an innovative method to facilitate sub-module power electronics, which is to integrate the power components into crystalline silicon (c-Si) PV cells. This approach has the potential to enable numerous design innovations. However, the fabrication processes of the integrated power electronics should be compatible with the PV cell fabrication methods. Moreover, only a limited amount of additional processing steps can be added with respect to standard solar cell manufacturing processes to achieve a cost-effective design. After reviewing previous research on this topic, we propose various new design possibilities for PV-cell-integrated diodes, transistors, capacitors, and inductors. Furthermore, we discuss the technical trade-offs and challenges that need to be overcome for successful industry adoption.

DISCUSSION

The process of regulating current and voltage flow and transforming it to a form appropriate for user loads is known as power electronics. A power electronic system with 100% efficiency and dependability is the ideal scenario.With all of its comforts, modern society heavily depends on the readily available, all-around supply of electric energy. The majority of physical labor is performed by electricity, which also supplies heating and lighting, initiates electrochemical reactions, and makes information gathering, processing, storing, and exchanging possible.Using electronic converters built on semiconductor power switches, power electronics is a subfield of electrical engineering that deals with converting and controlling electric power. A constant frequency and magnitude of ac voltage are provided by the power grid. Homes, offices, retail establishments, and other small buildings are often powered by single-phase, low-voltage power lines, but industrial plants and other major commercial facilities can access three-phase supply systems with a range of voltage levels.

The fixed-voltage, 60-Hz electric power can be viewed of as raw power, which must be modified for many applications (it is 50-Hz in the majority of other parts of the world).Conversion from ac to dc or vice versa as well as frequency and/or magnitude control of voltages and currents are all part of power conditioning. Using electric illumination as a simple illustration, an incandescent bulb can receive raw electricity immediately. A fluorescent light, on the other hand, needs an electronic ballast to start and maintain the electric arc. Thus, the ballast is a power conditioner required for the lamp to operate properly. When utilized in a theatre, the previously described incandescent bulb is powered by an AC voltage controller that enables light dimming immediately before the movie starts. Once more, this controller is an illustration of a power conditioner or power converter.

Batteries and solar and fuel cell sources are being used to supply raw dc power. The majority of photovoltaic energy systems are grid-connected, and the required power conditioning includes dc-to-ac voltage conversion and ac voltage management. When a dc source, such as in a golf cart or an electric wheelchair, powers an electric motor, a power electronic converter located between the battery and the motor controls voltage and enables reverse power flow during braking or downhill travel.The first mercury arc rectifiers were created around the beginning of the twentieth century, marking the beginning of power electronics. Rotating electro-machine converters were, however, mostly utilized in the past for the conversion and control of electric power.

An electric generator powered by an electric motor functions as an electro-machine converter. An AC motor drove a DC generator with a controlled output voltage if, for example, variable dc voltage had to be produced from fixed ac voltage. On the other hand, a speed-controlled dc motor and an AC synchronous generator were used if ac voltage was necessary and the supply energy came from a battery pack.These devices were obviously less convenient, efficient, and reliable than current static power electronic converters, which convert and regulate immobile energy.The following (such as maximum efficiency, maximum reliability, maximum availability, minimum cost, least weight, small size, etc.) are made possible by a power electronic system, which transforms electrical energy from one form to another.

Application of power electronics: Applications of Power Electronics are classified into two types Static Applications and Drive Applications.

Static Application: This makes use of welding, heating, cooling, and electro-plating as well as moving and/or rotating mechanical components.

Drive Application: Drive applications have rotating parts such as motors. Examples include compressors, pumps, conveyer belts and air conditioning systems.

Application of power electronics in real life:

1. Numerous everyday items that we use power electronics for include fan controllers, air conditioners, induction cooktops, light dimmers, emergency lights, vacuum cleaners, personal computers, UPS systems, battery chargers, and many more.
2. Power electronics are also widely utilised in automobile applications, such as forklifts, trolleys, subways, and hybrid electric cars. Modern automobiles themselves are examples of power electronics, as they contain parts like the ignition switch, adaptive front lighting, electric power steering, interior illumination and controls for the windscreen wipers. In addition to these, modern traction systems and ships frequently incorporate power electronics.
3. Since industries have large installations of high-power motors that are managed by power electronic drives, such as cement mills, rolling mills, compressor pumps, fans, lifts, textile mills, blowers, lifts, rotary kilns, etc., power electronics are employed in industries. Arc furnaces, welding, heating applications, construction equipment, excavators, emergency power systems, etc. are a few further applications.
4. In the aerospace and defence industries, power electronics are used to power aircraft, advance control in missiles, satellites, unmanned vehicles, space shuttles, and various other defence equipment.
5. Power electronics are employed in the production of renewable energy, such as solar, wind, and others, which requires power conditioning, conversion, and storage systems in order to be usable.

Types of Power Electronics Circuit: Power electronic circuits can fundamentally be divided into five categories, each of which is based on a distinct goal:

1. Rectifiers are used to change fixed AC to variable DC, such as full wave or half wave rectifiers.
2. Choppers are used to change fixed DC to variable DC.
3. Inverters are used to convert DC to AC with a configurable frequency and amplitude.
4. Voltage regulators are used to change fixed AC to variable AC at the same input frequency.
5. Cycloconverters are used to change fixed AC to AC with variable frequency.

Advantage of Power Electronics Converter:

Power electronic converters have the following advantages:

1. They last a very long time and are really dependable.
2. When employing electronic converters, there is relatively little power loss.
3. Power electronic converters are lightweight, compact, and efficient.
4. They also respond quickly.

Disadvantage of power electronics converter: Power electronic converter disadvantages include:

1. Power electronic converters have a limited capacity for overload.
2. Converters for power electronics are quite expensive.

Power semiconductor devices:

1. Power diodes
2. Power transistors (BJT's)
3. Power MOSFETS
4. IGBT's
5. Thyristors

A group of p-n-p-n structured power semiconductor switching devices are known as thyristors. Anode and cathode terminals are found on silicon p-n junction power diodes. Through alloying, diffusion, and epitaxial growth, P-N junctions are created. Modern diffusion and epitaxial techniques desired device properties are enabled through processes. The benefits of diodes include the following: outstanding mechanical and thermal stability elevated inverted voltage peak minimal reverse current low drop in forward voltage Efficiency at a high level.

Devices with regulated turn-on and turn-off properties are called power transistors. Because they are operated at the saturation area for switching purposes, these devices have a low on-state voltage drop. When a current signal is applied to the base or control 6 terminal, they turn on. As long as the control signal is there, the transistor remains turned on. Modern transistors, which are widely employed in dc-dc and dc-ac converters, have switching speeds that are far faster than thyristors. They are employed in low to medium power applications due to their lower voltage and current ratings than thyristors.

Power electronics module: A power electronic module, often known as a power module, is a grouping of various power components, primarily power semiconductor devices, which are suitably internal coupled to carry out a power conversion function. It is an integrated building block that can be used to create a power converter with fewer external parts needed. The power module package may contain control electronics for gate drivers, sensing, and protection purposes. The phrase "intelligent power module" is frequently used in this context.Due to the tight physical integration, the power module lowers parasitic components in the connection of the power semiconductor devices from an electrical standpoint. To eliminate the loss heat produced by power converter operation, the power module often incorporates a thermally conductive baseplate that can be fastened to a heat sink or a cold plate. It offers a sturdy mechanical package for the power components inside, from a mechanical aspect. An electro-thermomechanical device designed for power converter operation is a power module, to sum up.Because a power module design offers a sturdy mechanical construction and ensures proper functioning from an electric and thermal point of view as long as the module datasheet specifications and recommendations are followed, using one could simplify the design of a power converter. At higher power levels, where a discrete component solution would necessitate the paralleling of numerous power semiconductor devices, power modules are commonly employed.

CONCLUSION

We read about the importance of power electronics in our daily life and power electronics module. Electrical engineering's field of power electronics deals with the processing of high voltages and currents to provide power for a range of purposes. Power supply is transformed from one form to another, supplying regulated and controlled power, employing power semiconductor switches and control mechanisms. Power electronic systems are used in a variety of applications, such as generation, transmission, distribution, and power control. Different types of power electronics circuits (such as diodes, transistors, thyristors) is used to meet the distinct purposes of daily life.

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CHAPTER 2

POWER SEMICONDUCTOR DIODES AND TRANSISTORS

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ABSTRACT:

The essential ideas behind transistor and diode devices are covered in this chapter. Here is a quick explanation of the PN junction. We'll go into great detail on power bipolar transistors, power metal-oxide-semiconductor field-effect transistors (MOSFETs), and power insulated gate bipolar transistors (IGBTs). They are explained in terms of their physical makeup, static and dynamic traits, switching capabilities, and some of their uses.

KEYWORDS:

BJT, Diodes, IGBT, MOSFET, Power Semiconductors, Switches, Transistors.

INTRODUCTION

Power study of electronics integrates the fields of electricity (electric power), electronics, and control systems. The generation, transmission, and distribution of electric power involve both static and rotating power equipment. To achieve the desired control objectives (to control the output voltage and output power), electronics focuses on the study of solid state semiconductor power devices and circuits. An application of solid state power semiconductor devices (Thyristors) for the regulation and conversion of electric power is known as power electronics.Power electronics focuses on the research and development of thyristorized power controllers for a range of applications, including the control of heat, light and illumination, motor control for AC/DC motor drives used in industry, high voltage power supplies, vehicle propulsion systems and high voltage direct current (HVDC) gearbox.The process of regulating current and voltage flow and transforming it to a form appropriate for user loads is known as power electronics[1]. A power electronic system with 100% efficiency and dependability is the ideal scenario. Look at the block diagram that follows. It demonstrates the parts of a Power Electronic system and their connections. Figure 1 shows block diagram of dc power supply.

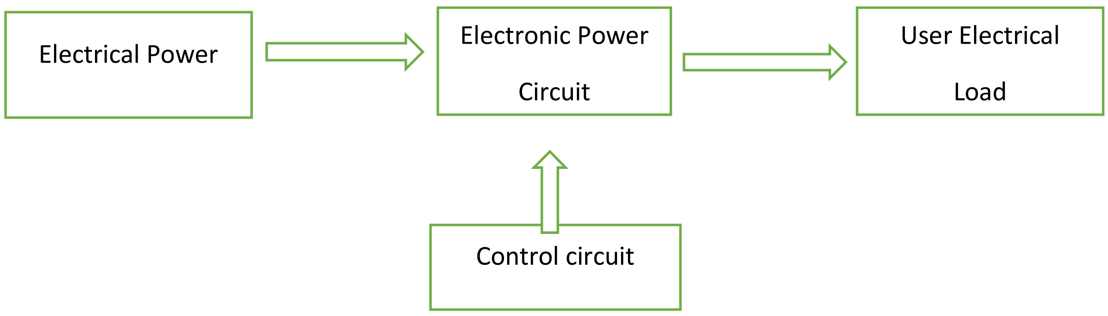

Figure 1: Block Diagram of DC power supply.

A power electronic system converts electrical energy from one form to another and ensures the following is achieved-

1. Maximum efficiency
2. Maximum reliability
3. Maximum availability
4. Minimum cost
5. Small size
6. Least weight

A power semiconductor device is a semiconductor component that is used in power electronics, such as a switch-mode power supply, as a switch or rectifier. Such a component is also known as a power device or a power IC when it is a part of an integrated circuit. A power semiconductor device is typically used in "commutation mode" (i.e., it is either on or off), and as a result, it has been designed with that usage in mind; linear operation is typically not recommended for such devices. Voltage regulators, audio amplifiers, and radio frequency amplifiers all frequently use linear power circuits. Systems delivering as little as a few tens of mill watts for a headphone amplifier all the way up to about a gigawatt in a high voltage direct current transmission line use power semiconductors[2].The electrolytic rectifier, of which an early model was reported by a French experimenter named A. Nodon in 1904, was the first electronic device used in power circuits. Because they could be quickly and cheaply made from aluminium sheets and common household items, they briefly enjoyed popularity among early radio experimenters. They were inefficient and had low withstand voltages.

In 1952, R.N. Hall introduced the power diode, the first germanium power semiconductor product. It could block 200 V of reverse voltage and could handle 35 A of current. Around 1952, germanium bipolar transistors with significant power handling capability (100 mA collector current), essentially the same structure as signal devices, but greater heat dissipation, were released. Power handling capacity developed quickly, and by 1954, 100-watt-dissipating germanium alloy junction transistors were available. All of these instruments operated at relatively low frequencies, up to 100 kHz, and at junction temperatures of up to 85 °C. Although silicon power transistors weren't produced until 1957, they had higher frequency responsiveness than germanium devices and could function at junction temperatures of up to 150 C when they were.

In 1957, the thyristor made its debut. It has a very high reverse breakdown voltage tolerance and a strong current-carrying capacity. The thyristor's drawback in switching circuits, however, is that once it is "latched-on" in the conducting state, it cannot be switched off by external control since the turn-off is passive, requiring that the device's power be cut off. Gate turn-off thyristors (GTO), a type of thyristor that may be switched off, were first demonstrated in 1960. These can be switched on or off with an applied signal, which allows them to circumvent some restrictions of the common thyristor[3].

Classification of semiconductor devices: One of the primary categories shown in Figure 1 may be applied to a power device:

A two-terminal device, such as a diode, whose condition is entirely determined by the external power circuit to which it is linked. In a triode or other three-terminal device, the signal on its driving terminal (also known as the gate or base), and its external power circuit both affect the device's state. A device with four terminals, such as the Silicon Controlled Switch (SCS). Anode, anode gate, cathode, and cathode are the names of the four layers and four terminals that make up the SCS type of thyristor. The first, second, third, and fourth layers, respectively, are linked to the terminals. A different categorization that is less evident but has a big impact on how well a gadget works is this:

A majority carrier device employs just one kind of charge carrier (e.g., a Schottky diode, a MOSFET, etc.).A minority carrier device utilizes both majority and minority carriers (i.e., electrons and electron holes) (e.g., a thyristor, a bipolar transistor, an IGBT, etc.).Although a minority carrier device can perform better on-state, a majority carrier device is quicker due to charge injection.

DISCUSSION

Semiconductor Power Equipment

1. Power diodes
2. BJT power transistors.
3. Power MOSFETS
4. IGBT devices.
5. Thyristors

A group of p-n-p-n structured power semiconductor switching devices are known as thyristors.

Power diodes: Anode and cathode terminals are found on silicon p-n junction power diodes. Through alloying, diffusion, and epitaxial growth, P-N junctions are created. The needed device properties are possible using modern diffusion and epitaxial methods. The benefits of diodes include the following: outstanding mechanical and thermal stability elevated inverted voltage peak minimal reverse current low decrease in forward voltage Efficiency at a high level[4].

Electrical transistors: Devices with regulated turn-on and turn-off properties are called power transistors. Because they are operated at the saturation area for switching purposes, these devices have a low on-state voltage drop. When a current signal is sent to the base or control terminal, they switch on. As long as there is a control signal, the transistor stays on. Modern transistors, which are widely employed in dc-dc and dc-ac converters, have switching speeds that are far faster than thyristors. They are utilised in low to medium power applications since their voltage and current ratings are lower than those of thyristors. The types of power transistors are as follows: o Insulated-gate bipolar transistors (IGBTs), Static Induction transistors (SITs), Metal-oxide semiconductor field-effect transistors (MOSFETs), bipolar junction transistors (BJTs).

Advantage of BJT:

1. BJTs have high switching frequencies because their turn-on and turn-off times are short.
2. A BJT's turn-on losses are minimal.
3. Because base drive control is an option, BJT has regulated turn-on and turn-offcharacteristics.
4. Commutation circuits are not necessary for BJT.

Disadvantages of BJT:

1. The BJT drive circuit is complicated.
2. It has a charge storage issue, which limits the switching frequencies.
3. Due to issues with the negative temperature coefficient, it cannot be employed in simultaneous operation.

Thyristor (Silicon Controlled Rectifier): A four-layer solid-state current-controlling device known as a silicon controlled rectifier or semiconductor-controlled rectifier. The brand name for a certain kind of thyristor used by General Electric is "silicon controlled rectifier".

Electronic equipment that need to regulate high voltage and power typically employ SCRs. As a result, they are suitable for medium and high AC power applications, including motor control. Similar to a diode, an SCR conducts when a gate pulse is supplied to it. It has four layers of semiconductors that may be either arranged to produce the NPNP or PNPN structures. Additionally, it contains three terminals (anode, cathode, and gate) and three junctions (J1, J2, and J3). Diagrammatic representation of an SCR is shown below in Figure 2 andFigure 3.

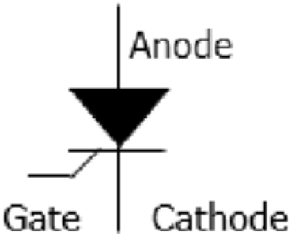

Figure 2: Symbol of Silicon Controlled Rectifier (tutorials point).

The anode connects to the P-type, cathode to the N-type and the gate to the P-type as shown below:

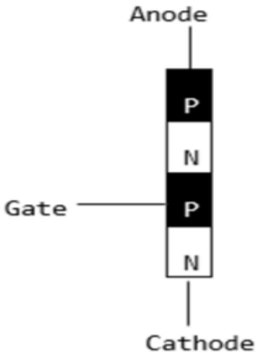

Figure 3: Symbol of P-N-P-N junction (tutorials point).

The inherent semiconductor in an SCR is silicon, which is then doped with the necessary dopants. However, the SCR application affects whether a P-N-P-N junction is doped.

Modes of operation of SCR:

(a) **OFF State (forward blocking mode):**In this case, the cathode is given a negative voltage, the gate is given a zero voltage, and the anode is given a positive voltage. Junctions J1 and J3 are therefore in forward bias, whilst Junction J2 is in reverse bias. J2 begins to conduct when it reaches its breakdown avalanche value. J1 is considered to be in the off state when its resistance is much higher than this value[5].

(b) **ON state (conducting mode):**An SCR enters this condition either by providing a positive signal at the gate or by raising the potential difference between the anode and cathode over the avalanche voltage. Gate voltage is turned off as soon as the SCR begins to conduct since it is no longer necessary to keep it in the ON state.

Reducing the current flow through it to the holding current value, which is the lowest possible value.

Putting a transistor across the junction will work.

(c) **Reverse blocking:**This makes up for the decrease in forward voltage. This is because a low-doped area in P1 is required. It's crucial to remember that forward and reverse blocking have equivalent voltage ratings.

TRIAC: Triode for Alternating Current is referred to by the abbreviation TRIAC. The word "TRIAC" refers to a semiconductor device having three terminals that regulates current flow. TRIAC is bi-directional whereas SCR is bi-directional, in contrast[6]. Due to its ability to regulate the current flow for both half of an alternating current cycle, it is perfect for operation using AC power for switching applications. The Figure 4 and Figure 5 below explains the conducting zone, symbol and the structure of TRIAC.

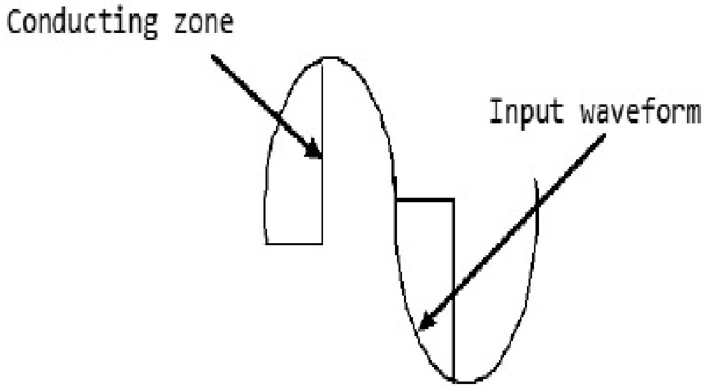

Figure 4: TRIAC

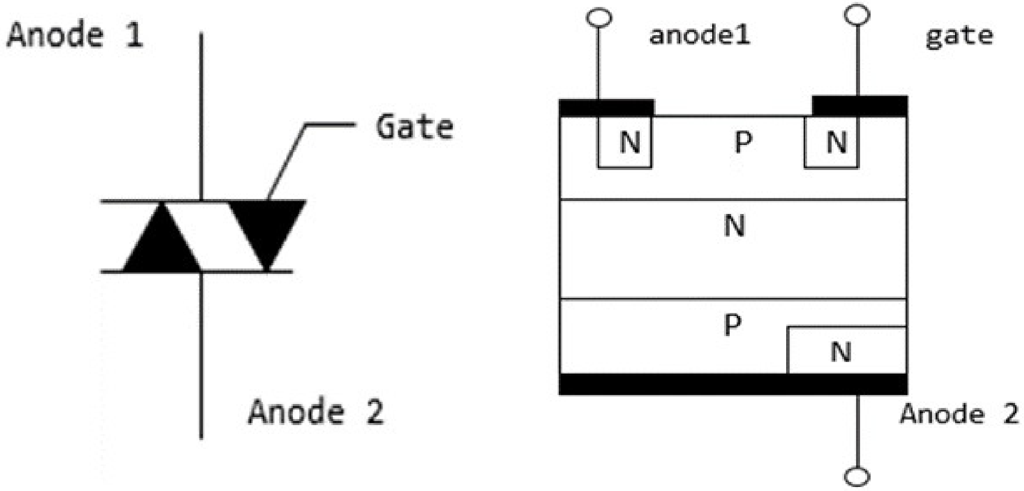

Figure 5: TRIAC symbol and structure. [mdpi]

As a DIAC with an additional gate contact added to guarantee device control, the TRIAC Structure is recognised as such. The TRIAC is made of silicon, just as other power devices. As a result, the fabrication of silicon results in the creation of less expensive electronics. The

TRIAC is divided into six areas, four of which are N-type regions and two of which are P-type regions.

Operation mode of TRIAC: The thyristor serves as the foundation for the TRIAC's functionality. It makes switching easier in AC electrical systems and components. Due to their ability to make advantage of both half of the AC cycle, they are frequently employed in light dimmers. They become more effective at using electricity as a result. Though it is technically conceivable to employ thyristors as TRIACs, doing so is not cost-effective for low-power activities. A TRIAC may be thought of as having two thyristors.

Due to the non-symmetrical switching that TRIACs display during operation, they are typically employed in applications that do not demand a lot of power. This has a negative impact on high power applications because it interferes with electromagnetic fields. Because of this, TRIACs are used to regulate speed in tiny electric fans, home light dimmers, and motor controllers[7].

BJT: BJT stands for Bipolar Junction Transistors. A BJT transistor relies on two semiconductors making contact for it to function. It can function as an oscillator, amplifier, or switch. Since it requires two different types of charge carriers—holes and electrons—for operation, it is referred to as a bipolar transistor. In P-type semiconductors, holes are the predominant charge carriers, whereas in N-type semiconductors, electrons are the dominating charge carriers.Two P-N junctions that are joined back to back and share a common region B base make up a BJT. This guarantees that connections are created in the base, collector, and emitter areas. The Figure 6 illustrate the NPN and PNP Transistor symbols.

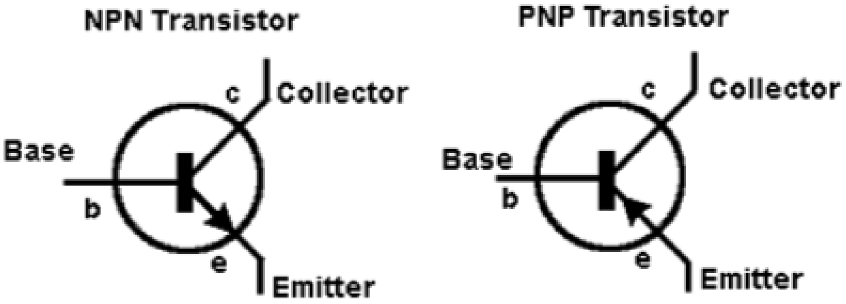

Figure 6: Symbol Of BJT. [mdpi]

IGBT: IGBT stands for Insulated Gate Bipolar Transistors, are semiconductor devices having three terminals that are mostly employed as switches in electronic equipment. It is a crucial part of contemporary products including light ballasts, electric autos, and variable frequency drives (VFDs) because of its quick switching and excellent efficiency. It may be used in amplifiers to process complicated wave patterns with pulse width modulation because to its quick on and off capabilities. In order to achieve high current and low saturation voltage capacity, IGBTs combine the traits of MOSFETs and BJTs. To get a control input, it combines an isolated gate utilising a FET Field Effect Transistor.

The ratio of an IGBT's output signal to its input signal is used to calculate the amplification of the device. The ratio of the output current to the input current determines the degree of gain in traditional BJTs. Compared to a MOSFET, an IGBT has a much lower ON state resistance (RON) value. This suggests that for a certain switching operation, the voltage drop (I2R) across the bipolar is quite small. The IGBT's forward blocking function is comparable to a MOSFET's. The current and voltage ratings of an IGBT are the same as those of a BJT when it is employed as a controlled switch in a static condition. In contrast, the isolated gate of an IGBT makes driving BJT charges simpler and so requires less power. Depending on whether the gate terminal is enabled or deactivated, the IGBT is turned ON or OFF. The IGBT is kept in the ON state by a consistent positive potential difference across the gate and emitter. The IGBT turns OFF when the input signal is gone[8].

The working principle of an IGBT only needs a minimal voltage to keep the device conducting. The IGBT can only turn ON in the forward direction because it is a unidirectional device.

This implies that, in contrast to MOSFETs, which are bi-directional, current travels from the collector to the emitter.Applications requiring medium to extremely high power levels, such as traction motors, require the IGBT. Large IGBTs have the capacity to handle huge currents of several hundred amps and blocking voltages as high as 6kv. Inverters, converters, and other appliances that need solid state switching also employ IGBTs as its power electronic component. High current and voltage bipolar are available. Their switching rates are, however, slow. MOSFETs, on the other hand, have fast switching rates despite their high cost.

MOSFET:A type of transistor used to switch electronic signals is a MOSFET, or Metal Oxide Semiconductor Field Effect Transistor.

The source S, drain D, gate G, and body B are its four terminals. The body of the MOSFET is often linked to the sources terminal, creating a three-terminal device that is comparable to other field effect transistors FET. Only three terminals are seen in electrical diagrams because these two major terminals are often linked together through short circuit. It is the element that both digital and analogue circuits use the most frequently[9]. A MOSFET requires less than one mille ampere of low current to turn on compared to a normal transistor. It produces a large current load of more than 50 Amperes simultaneously.

Operation of a MOSFET:

A small coating of silicon dioxide is present on MOSFETs, serving as the capacitor's plate. The isolation of the regulating gate causes the MOSFET's resistance to increase to nearly limitless levels. Since the gate terminal is blocked from the main current flow, the gate doesn't experience any current leakage. The n-channel and p-channel MOSFET is shown in Figure 7.

There are two primary state of MOSFETs-

(a) **Depletion state**:In order to turn the component OFF, the gate-source voltage (V_{GB}) is required. Given logic circuits use the device as a load resistor when the gate is at zero (V_{GB}), which is typically the case[10]. The threshold voltage of 3V for loading devices with N-type depletion causes the device to turn off by switching the gate at a value of -3V.

(b) **Enhancement state:**In order to turn the component ON in this condition, the gate-source voltage (V_{GB}) is necessary. The device is typically OFF when the gate is at zero (V_{GB}), but it may be turned ON by making sure the gate voltage is higher than the source voltage.

p-channel MOSFET

n-channel MOSFET

Figure 7: Illustrate the p-channel and n channel in MOSFET.

Comparison between BJT and MOSFET:

S.NO.	BJT	MOSFET
1.	It is a Bipolar Device.	It is majority carrier Device.
2.	Current control Device.	Voltage control Device.
3.	Output is controlled by controlling base current.	Output is controlled by controlling gate voltage.
4.	Negative temperature coefficient.	Positive temperature coefficient.
5.	So paralleling of BJT is difficult.	So paralleling of this device is easy.
6.	Dive circuit is complex. It should provide constant current (Base current).	Dive circuit is simple. It should provide constant voltage (gate voltage).
7.	Losses are low.	Losses are higher than BJTs.
8.	So used in high power applications.	Used in low power applications.
9.	BJTs have high voltage and current ratings.	They have less voltage and current ratings.
10.	Switching frequency is lower than MOSFET.	Switching frequency is high.

CONCLUSION

In this chapter we discuss about different type ofSemiconductor power equipment such as SCR, IGBT, MOSFET, BJT, etc and their working operation. Power semiconductor device is a semiconductor component that is used in power electronics, such as a switch-mode power supply, as a switch or rectifier. Such a component is also known as a power device or a power IC when it is a part of an integrated circuit. Voltage regulators, audio amplifiers, and radio frequency amplifiers all frequently use linear power circuits.

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CHAPTER 3

A BRIEF DISCUSSION ONPOWER DIODE

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ABSTRACT:

The power diode is arguably the most basic static switching device used in power electronics (PE). Its circuit symbol is a two-terminal device, with terminal A serving as the anode and terminal K serving as the cathode. In this chapter we will learn about different types of diodes, their current and voltage ratings, their series and parallel connections, and different applications of diodes. At the beginning, germanium and silicon were mainly used as semiconducting base materials. Silicon is nowadays the most frequently used base material for the production of diodes and thyristors.

KEYWORDS:

Current, Diodes, Power Diodes, Voltage.

INTRODUCTION

Diode as a switch: The power diode is arguably the most basic static switching device used in power electronics (PE). Its circuit symbol is a two-terminal device, with terminal a serving as the anode and terminal K serving as the cathode, as illustrated in Figure 1. The device is considered to be forward biased if terminal A has a greater potential than terminal K, and a forward current (IF) will flow through the device in the direction depicted. This results in a very little voltage drop across the device of around 1 V, which under ideal circumstances is often disregarded. A diode suffers a little current flowing in the opposite direction, known as the leakage current, when it is reverse biased, in contrast, and does not conduct. In a perfect diode, leakage current and forward voltage drop are both disregarded. A diode is typically regarded as the perfect static switch in PE applications.

A voltage drop occurs in the forward direction as a result of a potential barrier brought on by the distribution of charges close to the junction and other factors. For currents in the usual range, this is in the region of 1 V for silicon. Within the typical voltage working range, a very modest current that is mostly voltage independent flows in the opposite direction. For practical purposes, the static properties are frequently, which shows them. A threshold voltage VO and a linear incremental or slope resistance are used to represent the forward characteristic. Regardless of voltage within the usual operating range, the reverse characteristic is constant throughout the whole range of potential leakage currents. The static characteristics of power diode shown in Figure2.

Properties of PN junction: One can see from the forward and reverse biased state characteristics that current rises quickly as voltage increases when the diode is forward biased. Up until the breakdown voltage of the diode is achieved, the current in the reverse biased area is quite low. When the applied voltage exceeds this threshold, the current will quickly rise to a very high amount that is only constrained by an external resistance.

DC diode specifications. The following are the most crucial variables:

1. Forward voltage, or VF, is the voltage drop a forward biased diode experiences between A and K at a specific current level.
2. Breakdown voltage, abbreviated as VB, is the voltage drop across a diode at a specific current level when it is past the level of reverse bias. This is commonly referred to as an avalanche.
3. The current that is below the breakdown voltage is known as reverse current (IR).

AC Diode parameters: The following are some of the most popular parameters:

(a) Forward recovery time (t_{FR}) is the amount of time needed after the forward current begins to flow for the diode voltage to fall to a specific level.
(b) The reverse recovery time (t_{rr}), which is the period of time between the application of reverse voltage and the reverse current falling to a specific value.

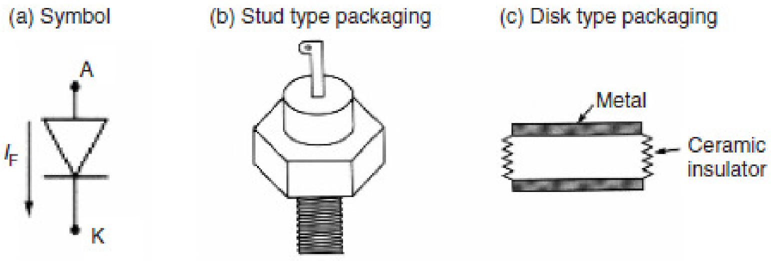

(a) Symbol (b) Stud type packaging (c) Disk type packaging

Figure 1: Power diode as a Switch.

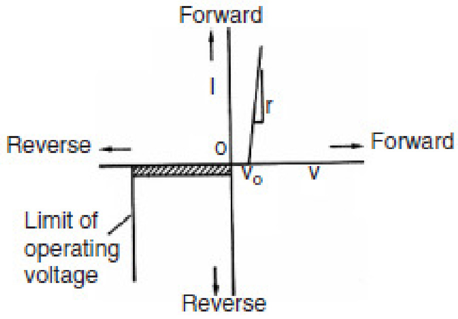


Figure 2: Static Characteristics of Power Diode.

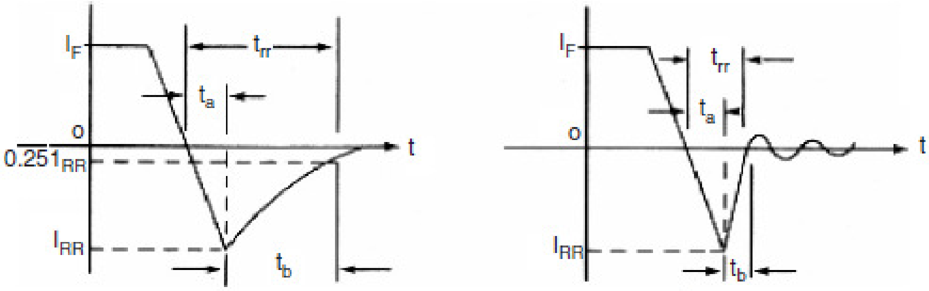
The time interval between the diode current's zero crossing and IRR is the parameter ta. On the other side, t_b represents the period of time between the greatest reverse recovery current and about 0.25 of IRR. The softness factor (SF) is the ratio of the two factors, t_a and t_b. For high frequency switching, diodes with abrupt recovery characteristics are utilised.

A design engineer must regularly determine the reverse recovery time in the real world. To assess the likelihood of high frequency switching, this is being done. As a general rule, the faster the diode can be switched, the smaller the t_{RR}.

$$t_{rr} = t_a + t_b$$

The following phrase is true if t_b is minimal when compared to t_a, which is a relatively common situation.

$$t_{RR} = \sqrt{\frac{2Q_{RR}}{(di/dt)}}$$



(a) Soft recovery (b) Abrupt recovery

Figure 3: Diode reverse recovery with various softness factors.

From which the reverse recovery current

$$I_{RR} = \sqrt{\frac{di}{dt}2Q_{RR}}$$

Where *QRR* is the storage charge and can be calculated from the area enclosed by the path of the recovery current.TheDiode reverse recovery with various softness factors is shown in Figure3.

Common Diode Type: The following key categories of diodes can be distinguished based on their intended uses:

The small signal diode: this diode is one of the semiconductor components that is utilised in a wide range of applications. They serve as a switch in wave-shaping, limiters, rectifiers, and capacitors in general-purpose applications. The forward voltage, reverse breakdown voltage, reverse leakage current, and recovery time are some typical diode characteristics a designer has to be aware of.

Silicon rectifier diodes: Diodes with a high forward current carrying capacity, often up to several hundred amps, are known as silicon rectifier diodes. Their reverse resistance is often in the mega-ohm region, whereas their forward resistance is typically merely a fraction of an ohm. Their main use is in power conversion, which includes power supplies, UPS systems, rectifiers and inverters, etc.Their casing temperature will increase if the current exceeds the rated value. The thermal resistance of stud-mounted diodes ranges from 0.1 to 1 C/W.

The Zener diode: Its main uses are in the control or reference of voltage. However, its temperature coefficient and impedance both affect how well it can sustain a particular voltage. Based on their avalanche features, Zener diodes are used as voltage references or regulators. These devices' resistance may rapidly decrease at a particular voltage while operating in reverse biased mode. This happens at the Zener voltage V_X, a known value to the designer.

A circuit utilising a Zener diode to regulate a linear power supply's reference voltage is shown in Figure 4. The transistor will send electricity to the load (output) circuit when it is working normally. The transistor base current will determine the output power level. When the Zener voltage reaches V_X, which will crush and limit the power supply to the load, a very high base current will force a significant voltage across the device.

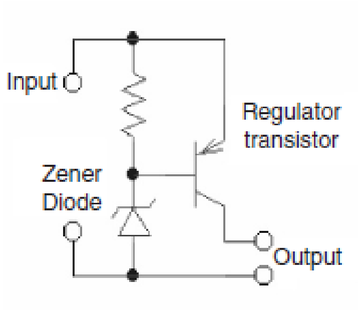


Figure 4: Voltage regulator with a Zener diode for reference.

Photo diode: Photons cause hole-electron couples to form when a semiconductor junction is exposed to light. Photocurrent is created when these charges spread over the connection. As a result, this gadget serves as a source of current that grows stronger with light intensity.

LED (Light Emitting Diode): High power versions of the frequently used components used in analogue and digital circuits are power diodes, which are utilised in PE circuits. They are produced in a huge variety and range. The voltage rating ranges from tens of volts to several thousand volts, while the current rating ranges from a few amperes to several hundreds.

DISCUSSION

Typical diode ratings:

Voltage rating: A particular datasheet for power diodes contains two voltage ratings.

The repeated peak inverse voltage (V_{RRM}) and the non-repetitive peak inverse voltage are the two types. The diode's capacity to prevent a reverse voltage that can occasionally happen as a result of an overvoltage surge is known as the non-repetitive voltage (V_{RM}). Repetitive voltage on the other hand is applied on the diode in a sustained manner [1], [2].

Current rating: Typically, heat sinks are used to install power diodes. This efficiently dissipates the heat produced as a result of ongoing conduction. So, depending on factors related to temperature rise, current ratings are calculated. A diode's datasheet typically lists three distinct current ratings. There are three of them: the average current, the maximum current, and the peak current. Each of these limits must be maintained, according to a design engineer. To achieve that, it is necessary to calculate, simulate, or measure the circuit's real current (average, rms, and peak). These values must be compared to those listed in the datasheet for the particular diode in question.

Snubber circuits for diodes: Diodes used in switching circuits require snubber circuits. It can prevent overvoltage spikes that could occur during the reverse recovery procedure and damage a diode. A capacitor and a resistor are connected in parallel with the power diode in a relatively typical power diode snubber circuit, as shown in Figure5.Due to a property, the capacitor will attempt to maintain the voltage across it, which is about equal to the voltage across the diode, while the reverse recovery current diminishes. On the other hand, the resistor will assist in dissipating part of the energy held in the inductor, which creates the IRR loop. You may compute the dv/dt via a diode as follows:

$$\frac{dv}{dt} = \frac{0.632 \times V_S}{\tau} = \frac{0.632 \times V_S}{R_S \times C_S}$$

The voltage supplied across the diode is V_S.

A diode's dv/dt rating is typically listed in the datasheet provided by the manufacturer. One may pick the value of the snubber capacitor C_S by knowing dv/dt and the R_S. It is possible to determine the R_S from the diode reverse recovery current:

$$R_S = V_S/I_{RR}$$

The designed *dv/dt* value must always be equal or lower than the *dv/dt* value found from the datasheet.

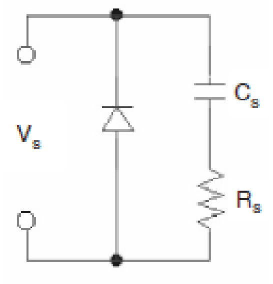


Figure 5: A Typical Snubber Circuit.

Series and parallel connection of power diodes: Diodes can be joined in series or parallel for specialised applications where the voltage or current rating of the selected diode is insufficient to fulfil the required rating. The structure will have a high voltage rating when connected in series, which may be required for high-voltage applications. The diodes must, however, be correctly matched, especially in terms of their reverse recovery capabilities. Otherwise, there can be significant voltage imbalances between the series-connected diodes during reverse recovery.

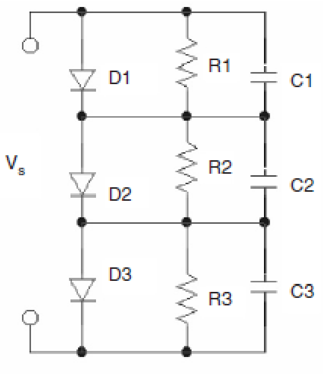


Figure 6: Series connected diodes with necessary protection.

Additionally, certain diodes may recover from the phenomena quicker than others, leading them to carry the entire reverse voltage, due to variances in the reverse recovery durations. As illustrated in Figure 6, all of these issues may be successfully resolved by adding a bank of capacitors and resistors in parallel to each diode. One can connect many diodes in parallel if the chosen one is unable to provide the necessary current rating. The designer must select diodes with the same forward voltage drop characteristics to achieve equitable current sharing. Additionally, it's crucial to check that the diodes are positioned on comparable heat sinks and are evenly cooled (if necessary). Individual diode temperatures will shift as a result, perhaps altering the diode's forward properties.

Typical applications of power diodes:

(a) **In Rectification:**An ac signal can be completely rectified using four diodes. This layout differs from conventional rectifier circuits in that it does not call for an input transformer. However, they are employed for seclusion and safety. Two diodes conducting simultaneously determine the current's direction. The current always flows in the same direction through the load. The complete bridge rectifier is the name of this rectifier scheme. Figure 7 illustrate the circuit arrangement of full bridge rectifier.

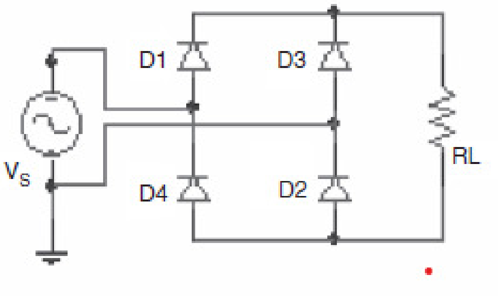


Figure 7: Full Bridge Rectifier.

Vm is the peak input voltage, while $V_{dc} = 2\ Vm / \pi$ is the average rectifier output voltage.

Vrms = Vm/ √ 2 is the rms rectifier output voltage.

When compared to a single phase rectifier, this rectifier is twice as efficient.

(b) **As Voltage Multiplier:**An ac signal can be doubled, tripled, or even quadrupled by connecting diodes in a specific way. Figure8 illustrates this. As is clear, the circuit will produce a dc voltage of 2Vm. To reach the maximum input voltage, the capacitors are alternately charged.

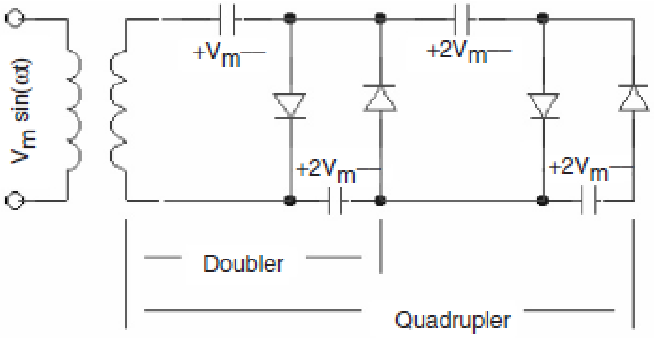


Figure 8: Voltage doubler and quadruple circuit.

(c) **For Voltage Clamping:**A voltage clamper is seen in Figure 9. The capacitor is charged to its maximum value in the direction that is indicated by the negative sinusoidal input voltage pulse. Due to the diode's open circuit, the capacitor cannot discharge after charging. Consequently, the output voltage

$V_o = V_c + V_i = V_m (1 + \sin(\omega t))$

The output voltage is restricted to a range between 0 and 2Vm.

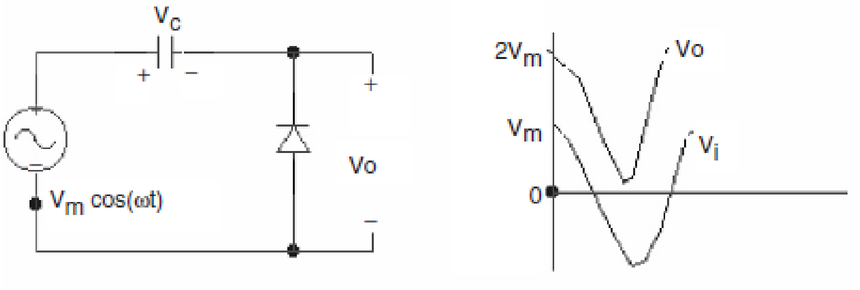


Figure 9: Voltage clamping with diode.

CONCLUSION

In this paper discussed about the power diodes in detail and properties of PN junction. The most common diode types are small signal diode, silicon rectifier diode, photo diode and light emitting diode and their current and voltage ratings discuss above. In addition we focused on snubber circuit of diode, series and parallel connections of diodes, and typical application of diodes {Formatting Citation}.

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CHAPTER 4

BASIC STRUCTURE AND OPERATION OF POWER BIPOLAR TRANSISTOR

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ABSTRACT:

The bipolar junction transistor is a solid-state device, and in these transistors, the current flow is regulated by the base terminal while also passing via the emitter and collector terminals. It is distinct from the other type of transistor, the field-effect transistor, in which the input voltage regulates the output current. The main advantages of bipolar junction transistors include High driving capability, High-frequency operation, high gain bandwidth, good performance at high frequency, maximum current density, low voltage drop, etc.

KEYWORDS:

BJT, Bipolar Transistor, Bipolar Junction Transistor, Junction Transistor, Power Transistor.

INTRODUCTION

In 1948, a group of scientists at the Bell Telephone Laboratories produced the first transistor, which quickly rose to prominence as a crucial semiconductor device. Only vacuum tubes were used for amplification prior to the invention of the transistor. Even though there are now integrated circuits with millions of transistors, each transistor is still necessary for the flow and regulation of all electrical energy. Power semiconductor switches are the brains of contemporary power electronics [1], [2]. These devices should be able to switch highly inductive loads that are measured in terms of safe operating area (SOA) and reverse-biased second breakdown (ES/b), have higher voltage and current ratings, instantaneous turn-on and turn-off characteristics, extremely low voltage drop when fully on, zero leakage current in blocking condition, be rugged to withstand high temperatures and radiation, and have high reliability.

The device's usefulness for some applications is constrained by the proper mix of these qualities. The operating voltage and current ranges for the most popular power semiconductor devices are shown in Figure 1 in terms of frequency. The plot actually provides a general overview of the industries where power semiconductors are typically used: high voltage and current ratings allow applications in large motor drives, induction heating, renewable energy inverters, high voltage DC (HVDC) converters, static VAR compensators, and active filters, while low voltage and high-frequency applications concern switching mode power supplies, resonant converters, and motion control systems, low frequency with hV ratings, and high frequency with hV ratings in active filters.

The standard part for powering many of those industrial applications is a power-npn or -pnp bipolar transistor. However, the development of the insulated gate bipolar transistor (IGBT) and the metal oxide field effect transistor (MOSFET) has made them competitive substitutes for the bipolar kinds. Bipolar-npn or -pnp transistors can still be employed in some performance applications because, for instance, they have lower saturation voltages across the operating temperature range. However, they are slower and have lengthy turn-on and turn-off times. The based driving circuitry is one of the most challenging design elements to overcome when a bipolar transistor is utilised in a totem-pole circuit. Bipolar transistors are current-driven despite having a lower input capacitance than MOSFETs and IGBTs. As a result, the drive circuitry has to produce large and sustained input currents.

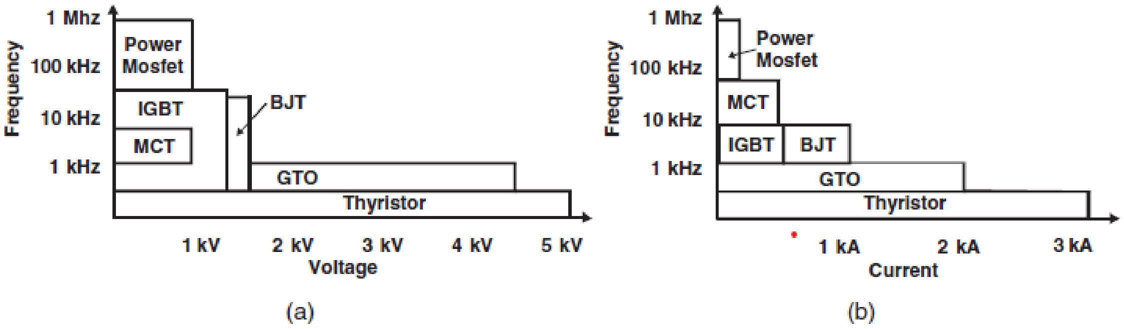

Figure 1: Power semiconductor operating regions; (a) voltage vs frequency and (b) current vs frequency.

The IGBT has an advantage over its bipolar equivalent in that it has a high input impedance. However, there is also a large input capacitance. The IGBT's input capacitor must thus be rapidly charged and discharged by the driving circuitry during the transition period. Even at operating temperatures, the IGBT's low saturation voltage performance is comparable to that of a bipolar power transistor. For dependable output switching, the IGBT requires a -5 to 10V gate-emitter voltage transition. There are several operational similarities between the MOSFET gate and IGBT. For example, to attain the same drive performance, both devices use less silicon than the bipolar power transistor and have high input impedances that are voltage-driven.

The MOSFET gate also has a large input capacitance, which puts the gate drive circuitry under the same demands as the IGBT being used at that time.When it comes to conduction loss vs supply-voltage rating, IGBTs perform better than MOSFETs. Compared to IGBTs, the saturation voltage of MOSFETs is much greater and less temperature-stable. For these reasons, insulated gate bipolar transistors (IGBTs) replaced bipolar junction transistors (BJTs) in a number of applications during the 1980s. Although the IGBT is a hybrid MOSFET/bipolar transistor with voltage control like a MOSFET and the output switching and conduction properties of a bipolar transistor, the early IGBT versions were prone to latch up, which was substantially eradicated.

The negative temperature coefficient of some IGBT types is another feature that makes it challenging to efficiently parallelize devices and can result in thermal runaway. These issues are now being resolved in the most recent IGBT versions. While comparing conduction loss vs. supply-voltage rating, outperform MOSFETs. Compared to IGBTs, the saturation voltage of MOSFETs is much greater and less temperature-stable. For these reasons, insulated gate bipolar transistors (IGBTs) replaced bipolar junction transistors (BJTs) in a number of applications during the 1980s. Although the IGBT is a hybrid MOSFET/bipolar transistor with voltage control like a MOSFET and the output switching and conduction properties of a bipolar transistor, the early IGBT versions were prone to latch up, which was substantially eradicated. The negative temperature coefficient of some IGBT types is another feature that makes it challenging to efficiently parallelize devices and can result in thermal runaway. These issues are now being resolved in the most recent IGBT versions.

It is abundantly evident that a classification based on switching frequency and voltage are two crucial factors in assessing whether a MOSFET or IGBT is the superior device in a given application. Selecting a part for usage in the crossover area, which encompasses voltages of 250–1000V and frequencies of 20–100 kHz, is still challenging. The BJT has been completely superseded by MOSFET in power applications at voltages below 500V, and it has also been supplanted in higher voltage applications where new designs employ IGBTs. The majority of typical industrial demands fall between the parameters of 200-500A conduction currents, 1-2 kV blocking voltages, and 10-100 ns switching times. Although new high-voltage projects have shifted away from BJTs in favour of IGBT in recent years, and it is anticipated that fewer new power system designs will use BJTs going forward, there are still some applications for BJTs. In addition, the BJT continues to be an active device due to its extensive installed base of equipment in various industries [3]–[5].

DISCUSSION

Basic structure and operation of BJT (Bipolar Junction Transistor): The three-region structure of n- and p-type semiconductor materials makes up the bipolar junction transistor (BJT), which may be built as either a npn or pnp device. A planar NPN BJT's physical composition is depicted in Figure 2. The operation is very similar to that of a junction diode, in which electrons from the emitter are injected into the base when the pn junction between the base and collector is forward-biased (VBE > 0). The reverse-biased base-collector junction (VBC 0), which has an electric field (depletion area), is where the electrons arrive since the base region is thin. When the electrons reach this junction, they are drawn through the depletion area and into the collector.

These electrons go from the collector contact out via the collector area. Being negative carriers, electrons allow positive current to flow into the external collector terminal when they move. Despite injecting holes from base to emitter, the forward-biased base-emitter junction does not add to the collector current; instead, it causes a net current flow component into the base from the external base terminal. As a result, the emitter current is made up of those two elements: holes injected from the base into the emitter and electrons intended to be injected across the base-emitter junction. According to the equation, the base-emitter voltage and emitter current have an exponential relationship.

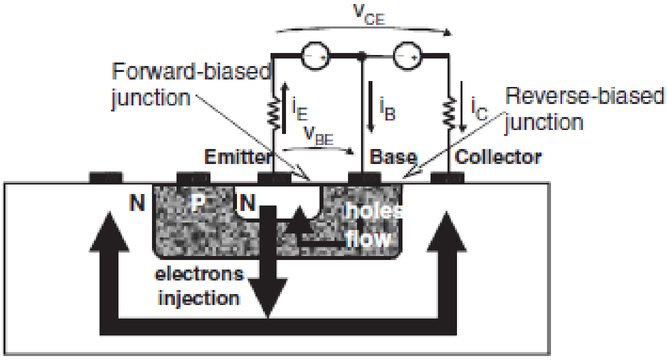

Figure 2: Structure of a planar bipolar junction transistor.

$$i_E = i_{E0}\,(e^{V}{}_{BE}/\eta V_T - 1)$$

Interleaving the emitters and bases of power transistors improves the device's resistance to second breakdown failure by lowering parasitic ohmic resistance in the base current channel. To obtain the largest current gain at a given current level, the transistor is often built to maximise the emitter periphery per unit area of silicon. They are made to be able to dissipate a lot of power and, consequently, have low thermal resistance, in order to ensure that those transistors have the highest potential safety margin. The chip size must be big for reasons such as these, and the emitter periphery per unit area is occasionally not optimised. Since aluminium metallization has numerous appealing features, including simplicity of application by vapour deposition and ease of definition by photolithography, the majority of transistor makers utilise it [6]–[8].

The fact that just a thin coating of aluminium can be placed using standard vapour deposition methods is a significant issue. This causes a voltage drop along the emitter fingers when large currents are applied, which lowers the injection efficiency on the parts of the periphery that are farthest from the emitter contact. Each finger can conduct just so much electricity as a result. It is feasible to reduce the resistance from the emitter contact to the functioning areas of the transistors the emitter periphery if copper metallization is used instead of aluminium.

Transistor Base Drive Applications: Many different circuits have been proposed as effective ways to control transistors in power electronics switching systems. Such base drive circuits make an effort to meet the following criteria: provide the appropriate collector current, adjust the base current to the collector current, and extract a reverse current from base to hasten device blockage. A solid base driver decreases commutation durations and overall losses, improving efficiency and frequency of operation. The base drive may be isolated or non-isolated kinds depending on the needs for grounding between the control and power circuits.

A non-isolated circuit is seen in Figure 3. T3 is kept off while T1 is turned on because T2 is driven and diode D1 is forward-biased to provide a reverse-bias. The power transistor TP is saturated by the positive base current IB. Due to the negative route given by R3 and -VCC, which provides a negative current for turning off the power, T3 turns on when T1 is turned off. The capacitor is discharged through T2, which forces a pulsed negative current from TP's base-emitter junction. To nearly completely eliminate storage time, a big reverse base drive and ant saturation methods may be combined.

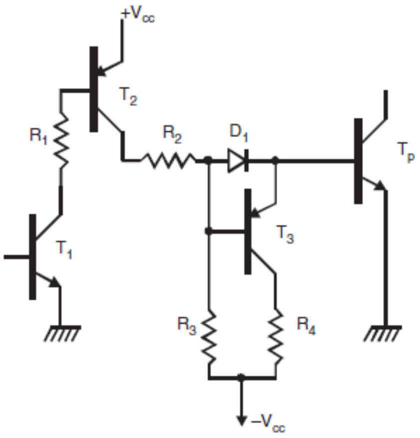

Figure 3: Non-isolated base driver.

It is possible to use the Baker's clamp circuit, as shown in Figure 5. The base of the transistor is two diode drops below the input while it is operating. The base will be 1.4V below the input terminal if diodes D_2 and D_3 have a forward-bias value of roughly 0.7V each. The collector is one diode drop, or 0.7V, below the input due to diode D_1. In order to avoid saturation, the collector will always be 0.7V more positive than the base. As a result, the gain will likewise gradually increase as the collector voltage rises. Reverse base current has a negative route thanks to diode D_4. A driver circuit like the one described in Figure5 is capable of supplying the input base current T_P transistor.

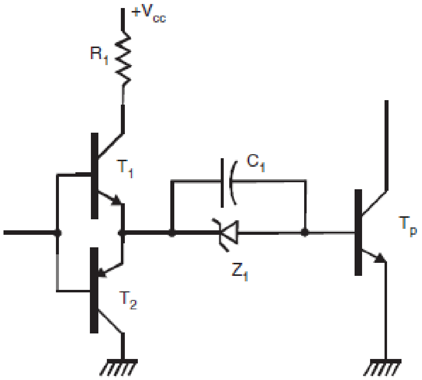

Figure 4: Base command without negative power supply.

Simple circuits like Figure. 4 can be employed in low power applications (step-per motors, tiny dc-dc converters, relays, pulsed circuits) when a negative power source is not available for the base drive. When the input signal changes from high to low, T1 turns on and a positive current flows to TP, keeping the capacitor charged with the Zener voltage. Numerous circumstances demand for floating transistor topologies, off-line operation, ground isolation, and isolated base drive circuits. Numerous circuits, most of which integrate base drive needs with their power transformers, have been proven in switching power supply isolated topologies. Circuits for isolated base drives can excite at a constant or proportional current.

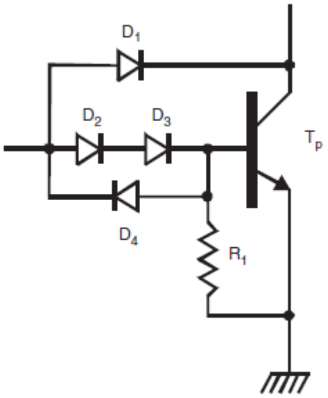

Figure 5: Ant saturation diodes (Baker's clamp) improve power transistor storage time.

Figure 6 is a base drive circuit for floating switching transistors that is extremely common. A positive current flows into the base of the power transistor TP, causing it to turn on, when a positive voltage is impressed on the secondary winding (V_S) of transistor $T_{R\ 1}$. Resistor R_1

restricts the base current. Because the diode D_1 reverse biased the base-emitter of T_1, T_1 is maintained blocked while the capacitor C1 is charged by (V_S-V_{D1}-V_{BE}). The capacitor voltage changes when VS is unzipped. The emitter of T_1 is brought to a negative potential in relation to its base by VC. As a result, T_1 is thrilled, turning on and beginning to draw a reverse current from TP base. Figure 7 depicts another extremely efficient circuit that uses the fewest amount of parts possible. A tertiary winding in the base transformer harnesses the energy that has been stored there to produce the reverse base current when the turn-off order is given. By including Baker clamp diodes or Zener diodes with paralleled capacitors into the isolated circuits, further combinations are also feasible.

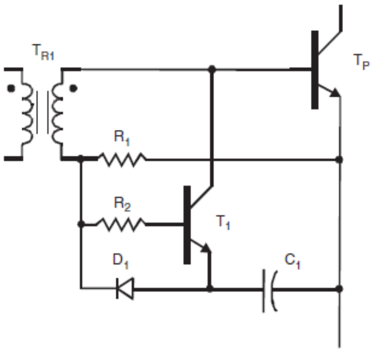

Figure 6: Isolated base drive circuit.

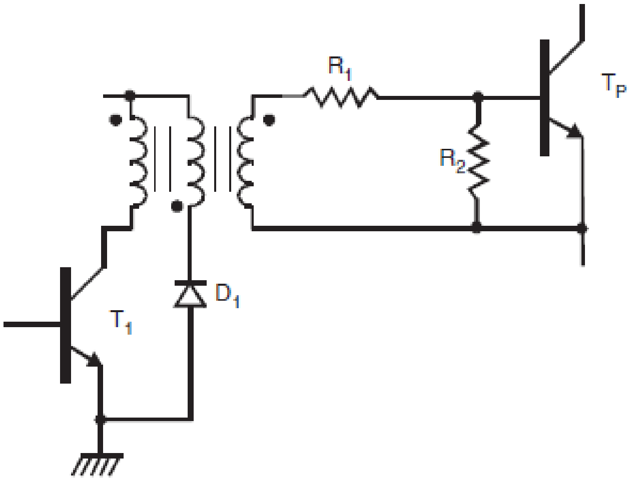

Figure 7: Transformer coupled base drive with tertiary winding Transformer.

Spice Simulation of Bipolar Junction Transistors:A general-purpose circuit simulation programme called SPICE may be used to model electrical and electronic circuits and forecast their behaviour. The Electronics Research Laboratory at the University of California, Berkeley first created SPICE in 1975. SPICE stands for Simulation Programme for Integrated Circuits Emphasis. A circuit's elements, nodes, variable parameters, sources, and values all need to be described. SPICE can perform a variety of circuit analysis, including:

1. Calculating the dc transference using a nonlinear dc analysis.
2. Analysing non-linear transients involves calculating signals as functions of time.
3. Linear ac analysis: creates a function of frequency bode graphic of the output.

4. Analysing noise.
5. Analysis of sensitivity.
6. Distortion analysis.
7. Fourier analysis.
8. Monte-Carlo analysis.

Additionally, PSpice offers analogue and digital libraries of common components including flip-flops, digital gates, and operational amplifiers. It may be used for a variety of analogue and digital applications as a result. Three sections make up an input file, or source file: (1) data statements that describe the circuit's components and connections; (2) control statements that specify the type of analysis SPICE should run on the circuit; and (3) output statements that specify the outputs that should be printed or plotted. The title statement and the end statement are two more statements that are necessary. The first line is the title statement, which may include any information, while the last line is invariably the end statement. END. This sentence must begin with a line be itself and end with a carriage return. There are also comment statements, which must start with an asterisk (*) and which SPICE ignores. For BJTs, there are several model equations.

The user simply has to enter the relevant model parameter values because SPICE already includes built-in models for semiconductor devices. The integral-charge model of Gummel and Poon serves as the foundation for the BJT model. As seen in Figure8, the model collapses to a piecewise-linear Ebers-Moll model if the Gummel-Poon parameters are not supplied. Both ways, it is possible to add charge-storage effects, ohmic resistances, and a current-dependent output conductance. The parameters IS and BF describe the forward gain characteristics, whereas IS and BR define the reverse gain characteristics. Additionally, there are three ohmic resistances: RB, RC, and RE. Voltage sources are used to simulate the two diodes, and Shockley's exponential equations can be changed into logarithmic ones.

On a separate document, a collection of device model parameters is defined. MODEL card with a specific model name applied. The model name is then referred to in the SPICE device element cards. The number of model parameters that must be entered on each device element card is reduced by this technique. The parameter name, which is shown below for each model type, is preceded by an equal sign before the parameter value is defined. The default settings for each model type are applied to model parameters that are not given a value.

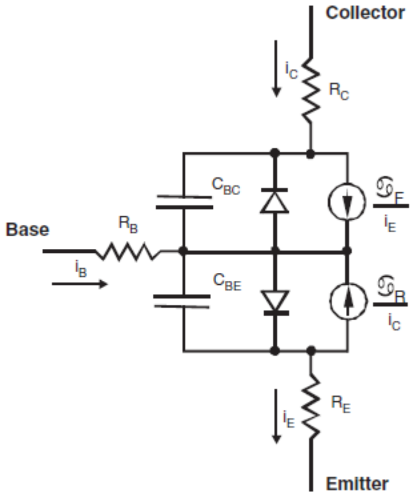

Figure 8: Ebers–Moll transistor model.

Basic applications of BJT: A wide range of power electronic applications, including switching mode power supply, dc motor inverters, and PWM inverters, to mention a few, use bipolar junction power transistors.

In Figure9, a fly back converter is demonstrated. The peak collector voltage at turn-off and the peak collector current at turn-on must both be supported by the switching transistor. The duty cycle must be kept relatively low, often below 50%, i.e. 6.0.5, in order to restrict the collector voltage to a safe value. The duty cycle is typically set at roughly 0.4, which restricts the peak collector. The working collector current at turn-on, which depends on the main transformer-choke peak current, the primary to-secondary turns ratio, and the output load current, is a second design requirement that the transistor must fulfil. When the transistor is turned on, the primary current builds up in the primary winding, storing energy. When the transistor is turned off, the secondary winding diode is forward biased, allowing the energy to be released into the output capacitor and load. Such a transformer is really known as a transformer-choke when it operates as a coupled inductor. Because the operation is unidirectional on the B-H characteristic curve, attention must be taken in the transformer-choke design of the fly back converter. As a result, a core with a sizable air gap and volume must be utilised. The ease with which a multiple output switching power supply may be produced is a benefit of the fly back circuit. This is such that only a diode and a capacitor are required for an additional output voltage as the isolation element serves as a common choke to all outputs [9]–[11].

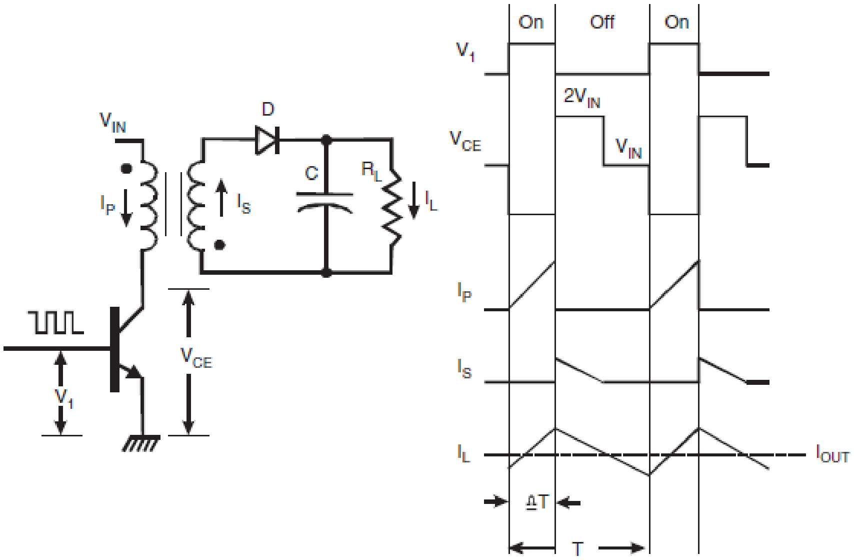

Figure 9: Flyback converter.

Advantage of BJT: The following are some of the key benefits of bipolar junction transistors.

1. High driving proficiency.
2. Operating at a high frequency.
3. An emitter-coupled logic from the digital logic family serves as a digital switch in BJTs.
4. Its bandwidth has a large gain.

5. At high frequency, it performs well.
6. Good voltage gain.
7. It features maximum current density and can run in low- or high-power applications.
8. Low forward voltage drop.

Disadvantage of BJT: The following are some of the key drawbacks of bipolar junction transistors.

1. Less thermal stability.
2. It makes more clamour.
3. The BJT is more of a radiation effect.
4. Fewer switching cycles.
5. Base management is intricate and demands careful handling.
6. When compared to a high voltage and current flashing frequency, the switching time is not quick.

CONCLUSION

This chapter provides information about bipolar junction transistors, including information on their kinds, benefits, uses, and properties. The bipolar junction transistor overview is what this article is all about. These are the most widely used amplifiers for all types of electrical signals found in discrete circuits, which are created without the use of integrated circuits (ICs). These come in a variety of sorts and forms, including BUH515, 2N3055, 2N2219, 2N6487, BD135, BD136, and 2N222.

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CHAPTER 5

POWER MOSFET AND SWITCHING IN ELECTRONIC CIRCUIT

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ABSTRACT:

Power MOSFET (metal oxide semiconductor field effect transistor) semiconductor switching devices will be described in general detail in this chapter. MOSFET is used in both analogue and digital circuits and is typically referred to as a transistor.Due to its high input impedance, low on-state resistance, and quick switching speeds, power MOSFETs are frequently utilised in electronic circuits for switching purposes. The function of Power MOSFETs, their properties, and their use in diverse applications are all covered in the chapter.

KEYWORDS:

Electronic Circuit, Input Impedance, ON-State Resistance, Power MOSFET, Switching.

INTRODUCTION

A MOSFET is a four-terminal electronic component with terminals for the source (S), gate (G), drain (D), and body (B). Typically, the source terminal and the body of the MOSFET are connected, creating a three-terminal device like a field-effect transistor. MOSFET is used in both analogue and digital circuits and is typically referred to as a transistor. This is a fundamental overview of MOSFET. And this device's main layout is as follows in Figure 1:

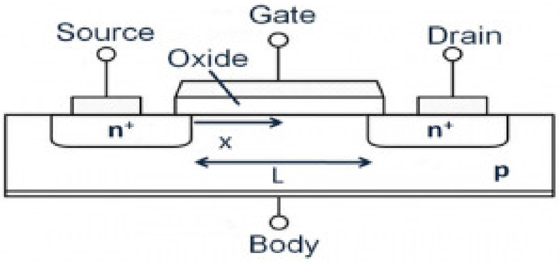

Figure 1: MOSFET With Terminals.

According to the MOSFET construction described above, the electrical fluctuations in the channel width and the flow of carriers (either holes or electrons) are what determine how well a MOSFET functions. Through the source terminal, the charge carriers enter the channel, and they leave through the drain.The voltage applied to the gate electrode, which is situated between the source and the drain, determines the channel's width. It is protected from the channel by a metal oxide layer that is very thin. The device's MOS capacity is the critical area across which the entire operation is spread [1], [2].

A MOSFET can function in two ways.

1. Depletion Mode
2. Enhancement Mode

Depletion Mode: The channel exhibits its maximal conductance when there is no voltage applied across the gate terminal. The channel conductivity diminishes when either a positive or negative voltage is applied across the gate terminal.

Enhancement Mode: The gadget is non-conducting when there is no voltage applied across the gate terminal. The gadget exhibits improved conductivity when the gate terminal is subjected to the maximum voltage.

Working Principle of MOSFET: The ability to regulate the voltage and current flow between the sources and drain terminals is the fundamental feature of a MOSFET device. The MOS capacitor underlies the device's operation, operating much like a switch. The main component of a MOSFET is a MOS capacitor. By applying either a positive or negative gate voltage, the semiconductor surface beneath the oxide layer, which is situated between the sources and drain terminal, may be inverted from p-type to n-type. The holes that are present underneath the oxide layer are pushed downward with the substrate when a repulsive force for the positive gate voltage is applied.The block diagram of MOSFET illustrated in Figure 2.

The area of depletion where the bound negative charges of the acceptor atoms are found. A channel forms after electrons are contacted. Additionally, the channel's positive voltage draws electrons from the n+ source and drain regions. Now, the current flows freely between the source and drain when a voltage is put between them, and the gate voltage regulates the channel's electron population. A hole channel will grow underneath the oxide layer if a negative voltage is applied instead of a positive one.

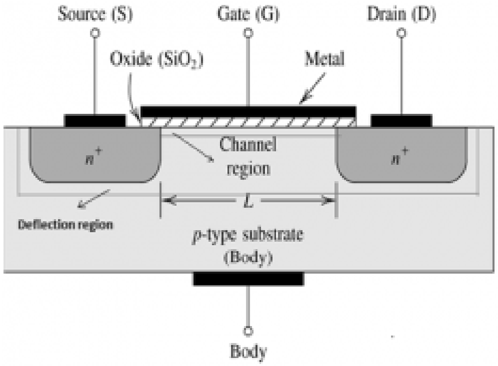

Figure 2: MOSFET Block Diagram.

P-channel MOSFET: Between the source and drain terminals of the P-channel MOSFET is the P-Channel area. The gadget has four terminals that are labelled gate, drain, source, and body. The body or substrate is of the n-type, whereas the drain and source are both strongly doped p+ regions. Positively charged holes are the direction in which current is flowing. The electrons residing under the oxide layer are pushed downward into the substrate when a negative voltage is applied to the gate terminal with repulsive force. The part of the depletion zone where the donor atoms' bound positive charges are present.

N-channel MOSFET: Between the source and drain terminals of the N-Channel MOSFET is an N-channel area. The gadget has four terminals: a gate, a drain, a source, and a body. The substrate or body of this type of field effect transistor is P-type, whereas the drain and source have strongly doped n+ regions. Negatively charged electrons in this type of MOSFET create the current flow. The holes located under the oxide layer are pushed downward into the substrate when the positive voltage is applied at the gate terminal with a repulsive force. The bonded negative charges connected to the acceptor atoms are found in the depletion zone.

The channel is created when electrons enter it. Additionally, the channel's positive voltage draws electrons from the n+ source and drain regions. Now, if a voltage is supplied between the source and drain, current can freely flow between them, and the gate voltage regulates the channel's electron population. A hole channel will grow underneath the oxide layer if negative voltage is applied instead of positive voltage [3]–[5].

DISCUSSION

MOSFET regions operation: According to the most likely scenario, this device's functioning mostly takes place in three areas, which are as follows:

Cut-off Region: This is the area where the device will be turned off and no current will flow through it. Here, the object serves as a fundamental switch and is used in this way whenever it is required for them to behave as electrical switches.

Saturation Region: In this region, the devices will maintain a constant drain-to-source current value without taking into account an increase in the voltage across the drain-to-source. When the voltage between the drain to source connection rises over the pinch-off voltage setting, this only occurs once. In this case, the device performs the role of a closed switch, allowing a saturated amount of current to pass from the drain to the source terminals. As a result, when the devices are meant to execute switching, the saturation region is chosen [6], [7].

Linear/Ohmic Region: This is the area where the voltage across the drain to source route increases as the current across the drain to source terminal increases. The MOSFET devices operate as amplifiers while they are operating in this linear zone. Now let's look into MOSFET switching characteristics.

A semiconductor that has an ON state and an OFF state functions primarily as switches. Examples of these semiconductors are MOSFETs and Bipolar Junction Transistors. Let's look at the ideal and actual properties of the MOSFET device to assess this functionality.

Characteristics of an ideal switch: A MOSFET must possess the following characteristics in order to serve as an excellent switch:

1. There must be the present limitation that it bears in the ON condition.
2. Blocking voltage levels should not be constrained in any way when the system is turned off.
3. The voltage drop value should be 0 when the device is turned on.
4. The resistance should be unbounded in the off state.
5. There shouldn't be any limitations on how quickly things may happen.

Characteristics of a Real Switch: The way a MOSFET functions may even be used in real-world applications because the universe is not only limited to ideal uses. In a real-world situation, the gadget should have the following characteristics.

1. The ability to manage power should be reduced in the ON state, which necessitates limiting the flow of conduction current.
2. Blocking voltage levels shouldn't be restricted in the OFF state.
3. The device's limiting speed and even its functioning frequency are constrained when it is turned ON and off for certain periods of time.
4. The MOSFET device will have very low resistance values in the ON state, which causes a voltage drop in the forward bias. Additionally, reverse leakage current is produced by a limited OFF state resistance.
5. The gadget loses power while it is ON and OFF when it is operating in a practical manner. Even in the transition phases, this occurs.

An illustration of a MOSFET Switch: In the circuit configuration shown below, an N-channel MOSFET in enhanced mode is utilised to switch a sample light between the ON and OFF positions. When a positive voltage at the transistor's gate terminal is supplied to its base, the lamp enters a on state (VGS = +v), or when a negative voltage level is used, the device enters an off state (VGS = 0). The Figure 3 illustrate a MOSFET switch below.

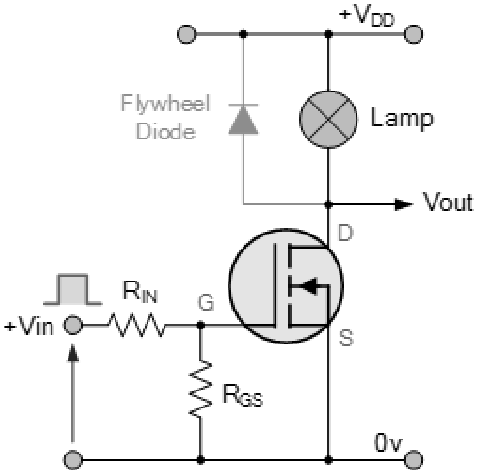

Figure 3: MOSFET as Switch.

If the lamp's resistive load were switched out for an inductive load and linked to a relay or diode that protects the load. A resistive load, such as a bulb or LED, is switched in the circuit above using a very basic circuit. But when employing a MOSFET as a switch with either a capacitive or inductive load, the MOSFET device needs to be protected. If the MOSFET is not safeguarded, it might cause the device to be damaged. The MOSFET must be switched between its cut-off zone, where VGS = 0, and saturation region, where VGS = +v, in order to function as an analogue switching device.

The acronym MOSFET, which stands for Metal Oxide Silicon Field Effect Transistor, can also be used to refer to a transistor. Here, the device's name alone made it clear that it could be used as a transistor. Both P- and N-channels will be present. A resistive load of 24 is linked in series with an ammeter and a voltage metre is placed across the MOSFET. The device is connected in this fashion utilising the four source, gate and drain connections. The source terminal of the transistor is linked to ground, and the current flow in the gate is positive. In contrast, the current flow in bipolar junction transistors occurs over the base-to-emitter circuit. However, because of the capacitor at the start of the gate, there is no current flow in this device; instead, it just needs voltage.

This can occur by continuing the simulation procedure and turning ON/OFF. There is no current flowing through the circuit while the switch is ON, but when the resistance of 24 ohms and the ammeter voltage are connected, we see that there is just a small voltage drop across the source since there is +0.21V across this component. RDS stands for resistance between drain and source. The voltage drop that occurs while current is flowing across the circuit is caused by this RDS. RDS fluctuates depending on the kind of device; depending on the type of voltage, it might range between 0.001, 0.005, and 0.05.

MOSFET Switch: When choosing a MOSFET as a switch, there are a few things to keep in mind. They are as follows:

1. Use of the P or N channel for polarity.
2. An operational voltage and current maximum rating.
3. When the channel is totally open, increased Rds. ON indicates that there is less resistance at the Drain to Source terminal.
4. Increasing the operating frequency.
5. To-220, DPAck, and many more types of packaging are available.

MOSFET Switch Efficiency: The increased drain current value that a MOSFET is capable of is the key limitation when using the device as a switching device. This indicates that the key factor determining the MOSFET's ability to switch is RDS in the ON state. It is expressed as the difference between the voltage at the drain and the voltage at the source. Only when the transistor is in the ON state does it need to be computed.

MOSFET Switch Used in Boost Converters: A switching transistor is often required for the operation of a boost converter. So MOSFETs are employed as switching transistors. These tools are used to determine voltage and current levels. Additionally, they are widely used when taking switching speed and cost into account.

The same is true with MOSFET, which has several applications. both of which are

1. With a MOSFET as a switch for an LED (remove the circle outline) with an Arduino.
2. Switching MOSFET for an AC load.
3. Dc motor MOSFET switch.
4. Switching a MOSFET for a negative voltage.
5. Using an Arduino to switch a MOSFET.
6. Switching a MOSFET with a microcontroller.
7. Hysteresis-equipped MOSFET switch.
8. Switch diode with active resistor MOSFET.
9. Equation for a MOSFET as a switch.
10. MOSFET switch for airsoft.
11. MOSFET switch with hysteresis.
12. MOSFET switch used as a switching solenoid.
13. MOSFET switch utilising an optocoupler.

Applications of MOSFETs as switches: Automatic brightness control in street lights is one of the best instances of this gadget being employed as a switch. These days, high-intensity discharge lamps are used in a large number of the lights that we see on roadways. However, utilising HID lighting requires more energy.There must be a switch for the alternate lighting technology, which is LED, because the brightness cannot be regulated based on the necessity. The shortcomings of high-intensity lighting will be solved by the use of LED systems. The fundamental idea behind its design was to utilise a microprocessor to directly control the lights on roadways.

All it takes to do this is change the clock pulses. This gadget is used to switch lighting based on the need. It includes a raspberry pi board on which a management processor is built in. In this case, LEDs can take the role of HIDs and are connected to the CPU through a MOSFET. After delivering the appropriate duty cycles, the microprocessor switches to a MOSFET to give a high degree of intensity.

Applications for MOSFETs include MOSFET amplifiers are extensively used in high frequency applications. These devices give the DC motor regulating. These are ideal for building chopper amplifiers since they have faster switching rates. MOSFET serves as a passive part for many electrical components.

Advantage of MOSFET: Several of the benefits include-

1. Even while operating at low voltage levels, it produces increased efficiency.
2. Since there is no gate current, the input impedance is higher, increasing the switching speed of the device.
3. These gadgets just require a little amount of electricity and power to operate.

Disadvantage of MOSFET: Several of the drawbacks include:

1. When these devices are operated at excess voltage levels, the device becomes unstable.
2. The thin oxide coating on the devices raises the possibility of device damage when driven by electrostatic charges.

Switching in Power ElectronicCircuits: The semiconductor-switching network is the brain of any power electronic circuit, as was previously mentioned. Is it necessary to employ switches in this situation to convert electrical power from the source to the load? Of course, the answer is no. Many circuits, such as linear regulators and power amplifiers, can execute energy conversion without switches. However, the effectiveness of the converter has a strong correlation with the requirement for employing semiconductor devices to carry out conversion activities. The semiconductor devices in power electronic circuits are often operated as switches, that is, either in the on-state or the off-state. Contrary to this, semiconductor components in linear regulators and power amplifiers work in the linear mode. As a result, before the processed energy reaches the output, a significant quantity of energy is wasted inside the power circuit. The ability of semiconductor switching devices to control and manipulate extremely large quantities of power from the input to the output with a relatively very low power consumption in the switching device makes their usage in power electronic circuits necessary. Consequently, a highly high efficiency power electronic system was produced.

Efficiency is regarded as a strong indicator of merit and has a big impact on the system's overall performance. Low power system efficiency results in significant heat dissipation, which may have one or more of the following effects:

1. As demand rises, energy prices rise as well.

2. Additional design challenges might be imposed, particularly with regard to how device heat sinks are made.

3. Low power density is caused by additional components like heat sinks, which raise the price, size, and weight of the system.

4. Low switching frequency is required by high power dissipation, which limits bandwidth, slows responsiveness, and—most importantly—retains the size and weight of capacitors and magnetic components (inductors and transformers). Therefore, switching at extremely high frequencies is always preferred.

But we'll demonstrate later that the average switching power dissipation rises as the switching frequency does. Therefore, a compromise must be made between decreased size, weight, and component cost vs reduced switching power dissipation, which calls for low switching frequency devices that are affordable.

5. Less reliable parts and apparatus: It has been demonstrated for more than 40 years that switching, whether mechanical or electrical, is the most effective approach to attain high efficiency. Electronic switches, as opposed to mechanical ones, are significantly more effective due to their durability, speed, and capacity to handle large amounts of electricity.

We should be aware that employing switches has advantages, but there are costs involved. Due to the nature of switch currents and voltages (square waveforms), the system typically produces high order harmonics. Additional input and output filters are typically added to the system to decrease these harmonics. Driver circuit control and circuit protection can also greatly increase the complexity of the system and its cost, depending on the device type and power electronic circuit architecture utilised [8].

CONCLUSION

Power MOSFETs are crucial parts of contemporary electronic circuits, especially in applications involving power switching. Compared to other switching devices like thyristors and bipolar junction transistors, they have a number of benefits. Power MOSFETs are ideal for use in circuits that need less power dissipation due to their high input impedance. Furthermore, the effective transmission of power in applications like power supply and motor control circuits is made possible by their low on-state resistance. Power MOSFETs are therefore often found in electronic devices, such as computers, TVs, and industrial machinery.

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CHAPTER 6

BASIC STRUCTURE OF THYRISTORS AND ITS OPERATION

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ABSTRACT:

Thyristors are semiconductor devices often utilised in electrical circuits for power management applications. A thyristor's fundamental composition is made up of three or more layers of alternating P- and N-type semiconductors. Forward blocking, forward conduction, reverse blocking, and reverse conduction are the four operating modes of the thyristor. Thyristors' capacity to regulate significant quantities of electricity makes them a common component in electronic circuits. The fundamental design, functioning, and applications of thyristors are covered in the chapter.

KEYWORDS:

Applications, Basic Structure, Thyristor, Power Control, Operation.

INTRODUCTION

Thyristors are solid-state semiconductor devices having four layers made of P and N type material. A gate conducts whenever it receives a triggering current up until the voltage across the transistor device is under forward bias. As a result, in this situation, it functions as a bistable switch. We must create a three lead thyristor by combining the tiny quantity of current with that current in order to manage the enormous amount of current flowing through the two leads. Control lead is the name of this procedure. A two lead thyristor is used to turn the device on if the potential difference between the two leads is below the breakdown voltage [1]–[3].

A thyristor's fundamental composition is made up of three or more layers of alternating P- and N-type semiconductors. Forward blocking, forward conduction, reverse blocking, and reverse conduction are the four operating modes of the thyristor. The thyristor functions as an open switch in the forward blocking mode, blocking current flow. The thyristor conducts current freely, similar to a closed switch, when it is in the forward conduction state. The thyristor once more functions as an open switch in the reverse manner when it is in the reverse blocking state. The thyristor conducts current in the opposite direction, much like a diode, when it is in reverse conduction mode.

Applying a positive voltage pulse to the thyristor's gate terminal will cause it to start conducting. The thyristor is activated and stays in the conducting condition until the current flowing through it reaches a certain threshold value. Power supply, motor control, lighting control, and voltage regulation are a few of the uses for thyristors. Triacs, Gate Turn-Off thyristors (GTOs), and Silicon Controlled Rectifiers (SCRs) are a few popular varieties of thyristors. They have a number of benefits over conventional power control devices, including the ability to handle large currents and voltages, switch quickly, and dissipate little power. Thyristors are crucial parts of electrical circuits for power control applications, to sum up. They have revolutionised the way we manage power in electronic circuits and have a number of benefits over existing power control devices. A thyristor has three different states.

1. **Reverse Blocking Mode:**The diode will block the applied voltage in this mode of operation.
2. **Forward Blocking Mode:**In this mode, a diode conducts when a voltage is supplied in a certain direction. Conduction won't take place in this instance though since the thyristor hasn't activated.
3. When a thyristor is in the forward conducting mode, current will flow through the device until the forward current falls below the holding current threshold. This is known as the "Holding current" condition.

Thyristor Layer Diagram:J1, J2, and J3 are the three p-n junctions that make up a thyristor.J1 and J3 will be in the forward bias state if the anode is at a positive potential in relation to the cathode and the gate terminal is not activated by any voltage. Reverse bias conditions will be present at the J2 junction. As a result, no conduction will occur at J2 junction, which will be in the off state. Avalanche breakdown for J2 happens if the voltage across the anode and cathode rises over the V_{BO} (Breakdown voltage), at which point the thyristor enters the ON state and begins to conduct. Figure 1 illustrates the thyristor layer diagram.

If a V_G (Positive voltage) is supplied to the gate terminal, a breakdown of low value V_{AK} occurs at junction J2. By choosing the right value for VG, the thyristor may be made to go into the ON state. The thyristor will conduct continuously under an avalanche breakdown scenario without taking gate voltage into account, up to and unless, either the holding current exceeds the current passing through the device or the potential V_{AK} is eliminated.Here, V_G stands for voltage pulse, which is the UJT relaxation oscillator's output voltage.

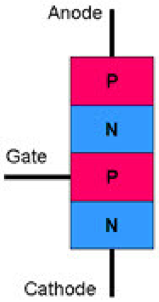

Figure 1: Thyristor Layer Diagram.

Thyristor switching circuits:

1. DC Thyristor Circuit
2. AC Thyristor circuit

DC Thyristor Circuit: We employ thyristors to regulate the greater DC loads and current when linked to the DC supply shows in Figure2. The fundamental benefit of using a thyristor as a switch in a DC circuit is that it provides a large gain in current. The thyristor is referred to as a current-operated device because it can regulate enormous quantities of anode current with a modest gate current.

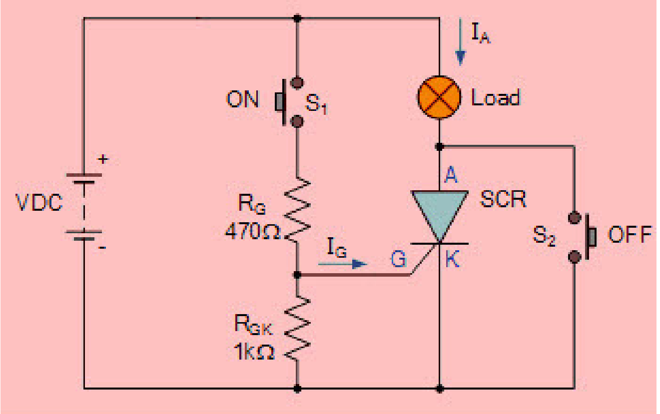

Figure 2: DC Thyristor Circuit.

AC Thyristor circuit: Because it is not the same as a circuit linked to a DC source, a thyristor behaves differently when connected to an AC supply shows in Figure 3. Thyristor employed as an AC circuit for one half of a cycle causes it to automatically shut off due to its reverse biased condition.

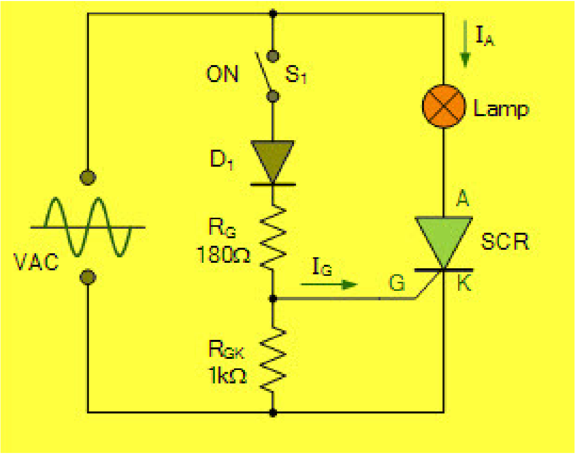

Figure 4: AC Thyristor circuit.

DISCUSSION

Types of thyristor: The majority of current research work has focused on further integrating the gating and control circuits into thyristor modules and using MOS technology to construct gate structures that are incorporated into the thyristor itself. The development of several versions on this topic should lead to certain technologies dominating the market in the years to come [4]–[6].You may find further information on the majority of the following discussion of thyristor types here.

SCRs and GTOs: Bipolar thyristors continue to be the devices with the highest power handling capacity. High powered thyristors have enormous diameters, some exceeding 100 mm, and as a result, have a di/dt rating that restricts the rate at which anode current may increase. Even when all of the stored charge injected during conduction has been eliminated, the rate of rise in forward voltage that may be applied is limited by the depletion capacitances around the p-n junctions, particularly the centre junction J2. A dv/dt limit is established by the related displacement current when forward voltage is applied while the thyristor is blocked. By adding a lateral high resistivity zone to help disperse the energy during break over, some work is being done to improve the voltage hold-off capabilities and over-voltage protection of traditional SCRs. However, due to their controllability, high performance GTOs and IGCTs are now receiving the majority of the attention, whereas optically triggered architectures with gate circuit isolation are receiving less attention.Thick n-base regions are necessary for high voltage GTOs with symmetric blocking capabilities in order to support the strong electric field.Due to the smaller n-base needed, the insertion of an n+ buffer layer adjacent to the p+-anode enables high voltage forward-blocking and a low forward voltage loss during conduction.

To make it easier to remove extra carriers from the n-base during turn-off while maintaining strong blocking capabilities, cylindrical anode shorts have been included. This device construction has a 6 kV hold-off and can manage 200 A at 900 Hz. In these architectures, some of the design trade-offs between the n-base width and turn-off energy losses have been identified. A comparable GTO with an n+-buffer layer and pin structure has been created, and it has the capacity to manage up to 1 kA (at a forward drop of 4V) and 8 kV of forward blocking. A reverse conducting GTO that can interrupt a peak current of 3 kA, block 6 kV in the forward direction, and have a turn-off gain of roughly 5 has been created.

A modified GTO structure is the IGCT. Its design and production ensure that the whole cathode current is commutated away from the cathode area and directed away from the gate contact. The IGCT's construction is comparable to that of a GTO, with the exception that there is always a low-loss n-buffer zone between the n-base and p-emitter. The IGCT device package is combined with a specifically created gate-drive circuit and is made to provide a very low parasitic inductance. The only connections needed are a low-voltage power source for the gate drive and an optical signal for gate control because the gate drive already has all the necessary di/dt and dv/dt safeguards.The IGCT may run without a snubber circuit and switch with a greater anode di/dt than a comparable GTO thanks to specifically designed gate drive and ring-gate packaging circuit.

In comparison to a traditional GTO, the IGCT performs better at blocking voltages of 4.5 kV and higher. The peak snubberless turn-off capability of the IGCT is directly correlated with the rate at which the cathode current is redirected to the gate (diGQ/dt). For turn-off, the gate drive circuit may sink current at diGQ/dt values greater than 7000 A/s. With this hard gate drive, a low charge storage time of around 1 s is obtained. For high-power, high-voltage series applications, such as high-power converters exceeding 100MVA, static volt-ampere reactive (VAR) compensators, and converters for dispersed generation like wind power, the IGCT is appealing due to its short storage time and fail-short mode.

MOS-controlled Thyristors: An inversion layer is created in the n-doped material when the MCT is in its forward-blocking state and a negative gate-anode voltage is applied, allowing holes to travel laterally from the p-emitter (the p-channel FET source) across the channel to the p-base (the p-channel FET drain). The base current for the NPN transistor is represented by this hole flow. The p-emitter then injects holes into the n-base in response to the n-emitter's injection of electrons, turning on the PnP transistor and latching the MCT. A positive gate-anode voltage is used to remove the MCT from conduction. The Cross section of unit cell of a *p*-type MCT in Figure5.

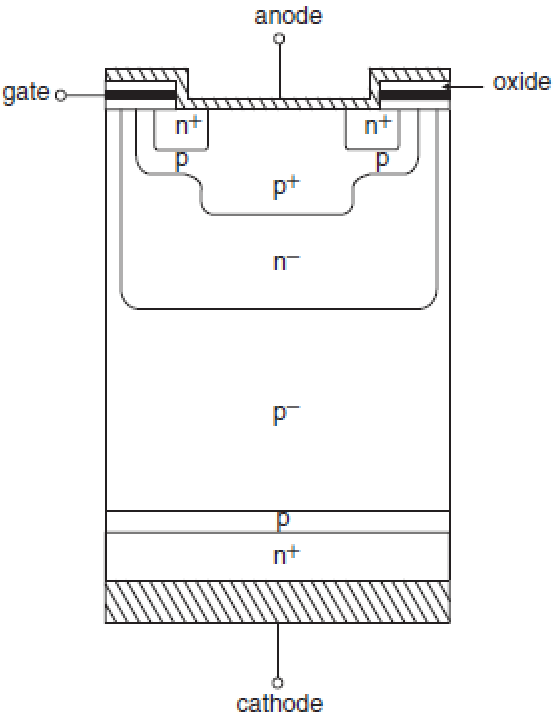

Figure 5: Cross section of unit cell of a *p*-type MCT.

This signal produces an inversion layer that directs n-base electrons towards the anode's strongly doped n-region instead of the p-emitter. The base current of the PnP transistor is diverted by this n-channel FET current, causing the base-emitter junction to dissipate. After then, the p-base is no longer able to gather holes. The NPN transistor turns off when this hole current also known as the base current is eliminated. Recombining with the remaining stored charge, the MCT enters its blocking state.

Even though MCTs are capable of handling two to five times the conduction current density of IGBTs, their performance, notably their capacity to withstand current interruption, is still constrained by the apparent diversity in the turn-off FET structure's construction. Ensembles of cells are susceptible to current filamentation during turn-off, according to numerical modelling and its experimental confirmation. The issue of current interruption capability affects all MCT device designs. In contrast, turn-on is rather straightforward; the MCT's turn-on and conduction characteristics are close to the one-dimensional thyristor limit.

The emitter switched thyristor (EST) and dual-gate emitter switched thyristor (DG-EST) are two more variants on the MCT structure that have been proven. These consist of integrated lateral MOSFET structures that join an n+ thyristor cathode area to a floating n-emitter region. The MOS channels are connected in series with the floating n-emitter area, allowing electrons from the n-base to activate the thyristor and interrupting the current to start the turn-off process. The two gates enable an IGBT mode to run during switching and a thyristor mode to operate in the on-state of the DG-EST, which functions as a dual-mode device.

Static Induction Thyristors:A cross section of a SITh or FCTh resembles that in Figure 6. Surface gate architectures can be found in other SITh topologies. Basically a pin diode, the device has a gate construction that can choke off anode current passage. High power SIThs feature a sub-surface gate (buried-gate) configuration that enables the use of bigger cathode surfaces and, consequently, greater current densities.

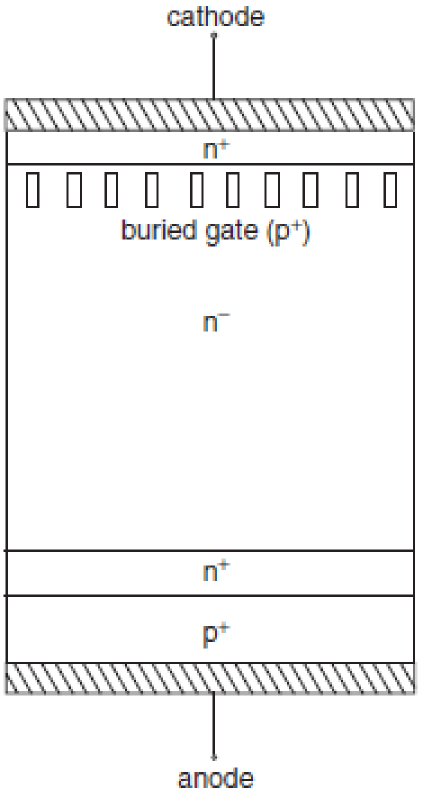

Figure 6: Cross section of a SITh or FCT.

While step-gate (trench-gate) structures may block up to 4 kV and conduct 400 A, planar gate devices have been made with blocking capacities of up to 1.2 kV and conduction currents of 200 A. Similar devices have been shown to block 2 kV and conduct 200 A, with claims of up to 3.5 kV blocking and 200 A conduction. These devices feature a "Verigrid" construction. Additionally, buried-gate devices that conduct 300A and block 2.5 kV have been created. For fabrication in SiC, there has recently been a renaissance of interest in these devices [7]–[9].

Optically Triggered Thyristors: In power utility applications where series stacks of devices are essential to reach the high voltages required, optically gated thyristors have typically been employed. The development of this class of devices, which are normally offered in ratings from 5 to 8 kV, has been motivated by the need for isolation between gate drive circuits for circuits like static VAR compensators and high voltage dc to ac inverters (for use in high voltage dc (HVDC) transmission). The cross section resembles that in Figure7, which shows the amplifying gate structures and the photosensitive area. Over-voltage protection may also be included into light-triggered thyristors (LTTs).

One of the most contemporary devices has a trigger power need of 10mW and can block 6 kV in both the forward and reverse directions, conduct 2.5 kA on average, maintain a di/dt capability of 300 A/s, and a dv/dt capability of 3000 V/s. It has proven possible to create an integrated light-triggered and light-quenched SITh that can block 1.2 kV and conduct up to 20 A (at a forward drop of 2.5V).This device combines a typically off p-channel darlington surface-gate static induction phototransistor with a normally off buried-gate static induction photothyristor. Less than 5 and 0.2 mW, respectively, are needed for the optical trigger and quenching, respectively.

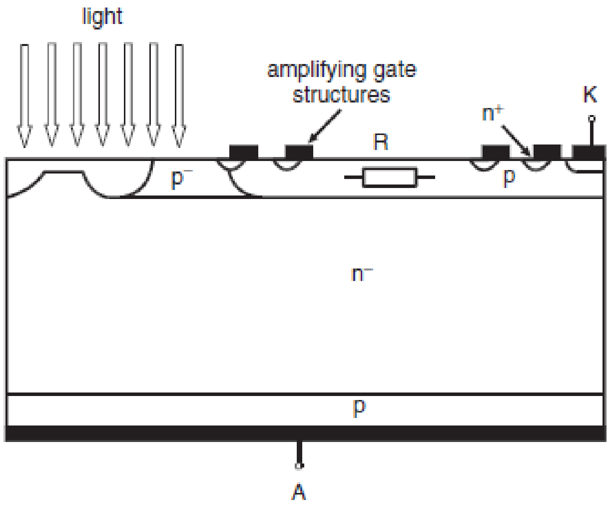

Figure 7: Cross section of a light-triggered thyristors (LTT).

Bidirectional Triode Thyristors or TRIACs: TRIAC is a three terminal semiconductor device used for regulating current. It comes from the word "triode" for an alternating current. While TRIACs may conduct in both ways, thyristors can only do so in one direction. A TRIAC or a pair of back-to-back coupled thyristors can be used to alter the AC waveform for both sides. One thyristor is used to turn on one cycle, while reverse connected thyristors are used to operate the other cycle [10]–[12].

CONCLUSION

Thyristors are crucial parts of electronic circuits that need to regulate large amounts of power, such as circuits for power supply, motor control, and lighting. They are superior to conventional power control devices in a number of ways because of their high current and voltage handling capabilities. A thyristor's fundamental composition is made up of three or more layers of alternating P- and N-type semiconductors. Forward blocking, forward conduction, reverse blocking, and reverse conduction are the four operating modes of the thyristor. The thyristor shifts from the blocking state to the conducting state when a gate signal is provided, enabling a significant amount of current to flow through the component. Thyristors come in a variety of kinds, including SCR, TRIAC, and GTO, and may be used in both AC and DC circuits. In conclusion, thyristors have revolutionised how we regulate power in electronic circuits and are essential in power control applications.

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CHAPTER 7

DIODE RECTIFIERS AND SINGLE-PHASE RECTIFIER

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ABSTRACT:

Electronic devices are used diode rectifiers to change alternating current (AC) into direct current (DC). They are extensively utilised in many different electrical equipment, including rectifiers, inverters, and power supply. The several types of diode rectifiers including half-wave, full-wave, and bridge rectifiers as well as their operational concepts, benefits, and drawbacks are covered in this chapter. It also discusses a few typical uses for diode rectifiers.

KEYWORDS:

Alternating Current, Bridge, Direct Current, Diode, Full Wave Rectifier, Half Wave Rectifier.

INTRODUCTION

A rectifier diode is a semiconductor diode used in the rectifier bridge application to correct AC (alternating current) to DC (direct current). Digital electronics place a high priority on the rectifier diode through Schottky barrier option. This diode can handle voltages of up to a few kV and currents ranging from a few mA to a few kA. Silicon is a good material for creating rectifier diodes since it can conduct high electric current values. Although not well-known, these semiconductor diodes still employ gallium arsenide. Both the allowed reversed voltage and junction temperature are lower for Ge diodes. A benefit of the Ge diode over the Si diode is its low threshold voltage value while working in forward bias [1]–[3].

Diode rectifier circuit use and design are covered in this chapter. It includes high-frequency rectifier circuits as well as single-phase, three-phase, and poly-phase rectifier circuits. This chapter's goals are to:

1. Empower readers to comprehend how conventional rectifier circuits work;
2. Empower readers to recognise the various rectifier attributes needed for various applications;
3. Empower readers to create useful rectifier circuits.

The high-frequency rectifier waveforms provided are derived from PSPICE simulations that account for the collateral damage caused by stray and parasitic components. The waveforms can then closely mimic actual waveforms in this way. The realistic voltage, current, and other ratings of high-frequency rectifiers may be determined with the aid of these waveforms, which is very helpful for designers.

Rectifier Diode Circuit Working: A unique production method resulted in the chemical fusion of both the n-type and p-type materials, forming a p-n junction. Due to the fact that this P-N junction contains two terminals that may be considered electrodes, it is referred to as a "DIODE" (Di-ode). Biasing occurs when an external DC supply voltage is supplied to an electronic device through its terminals.

Diode Rectifier without Bias: A rectifier diode is referred to as an Unbiased Diode if there is no voltage applied to it. The N-side will have a majority of electrons and a very small number of holes owing to thermal excitation, whereas the P-side will have a majority of charge carriers holes and a very small number of electrons. Free electrons from the N-side of the diode will diffuse (spread) into the P side during this process, recombining in holes there to produce -ve immobile ions on the P side and +ve immobile ions on the N-side. At the connection edge on the n-type side is the immobile. The immobile ions in the p-type side close to the junction edge are similar. As a result, both positive and negative ions will collect in large quantities near the junction. Depletion region is the name given to this newly created territory. At this location, the PN junction of the diode is crossed by a static electric field known as the Barrier Potential. It prevents holes and electrons from moving farther across the junction.

Diode with Forward Bias: A PN junction diode is said to be in forward bias state when the positive terminal of a voltage source is connected to the p-type side and the negative terminal is connected to the n-type side shown in Figure 1. The DC voltage supply's negative terminal repels the electrons, which cause them to gravitate towards the positive terminal. Therefore, this electron drift causes current to flow in a semiconductor when applied voltage is present. "Drift current" is the name given to this current. Since electrons make up the bulk of the carriers, the current in n-type is electron current. Since holes make up the bulk of p-type carriers, they are attracted to the positive terminal of the DC supply and migrate away from it in the direction of the negative terminal. Therefore, the hole current is the current in the p-type. Thus, a forward current is produced by the total current caused by the majority of carriers. The direction of conventional current is the opposite of the flow of electrons, flowing from positive to negative of the battery [4].

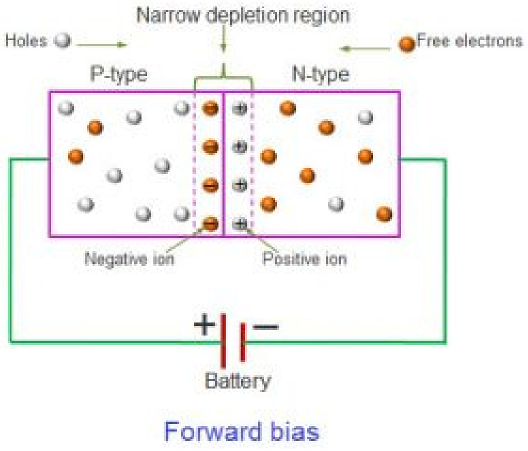


Figure 1: forward bias diode (elprocus).

Reverse Biased Diode: If the diode's n-type end is linked to the positive terminal of the source voltage and its negative terminal is attached to the p-type end, then the only current that flows through it is reverse saturation current shows in Figure 2. This is due to the fact that under reverse bias, the depletion layer of the junction widens as the reverse-biased voltage increases. Minority carriers in the diode cause a little current to pass from the n-type to p-type end. Reverse Saturation Current is the name given to this current. In p-type semiconductors and n-type semiconductors, respectively, minor carriers are mostly produced thermally. Now, if the reverse applied voltage across the diode is gradually raised, the depletion layer will eventually be destroyed, which will result in a significant rise in the reverse current flowing through the diode.

The diode may be irreversibly damaged if this current is not externally restricted and it exceeds the safe amount. The device's other atoms are struck by these quickly travelling electrons, removing more electrons from them as a result.

By rupturing the covalent bonds, the electrons that were already freed liberate even more electrons from the atoms. The flow of current via the p-n junction is significantly increased as a result of this procedure, known as carrier multiplication. Avalanche Breakdown is the name of the linked phenomena.

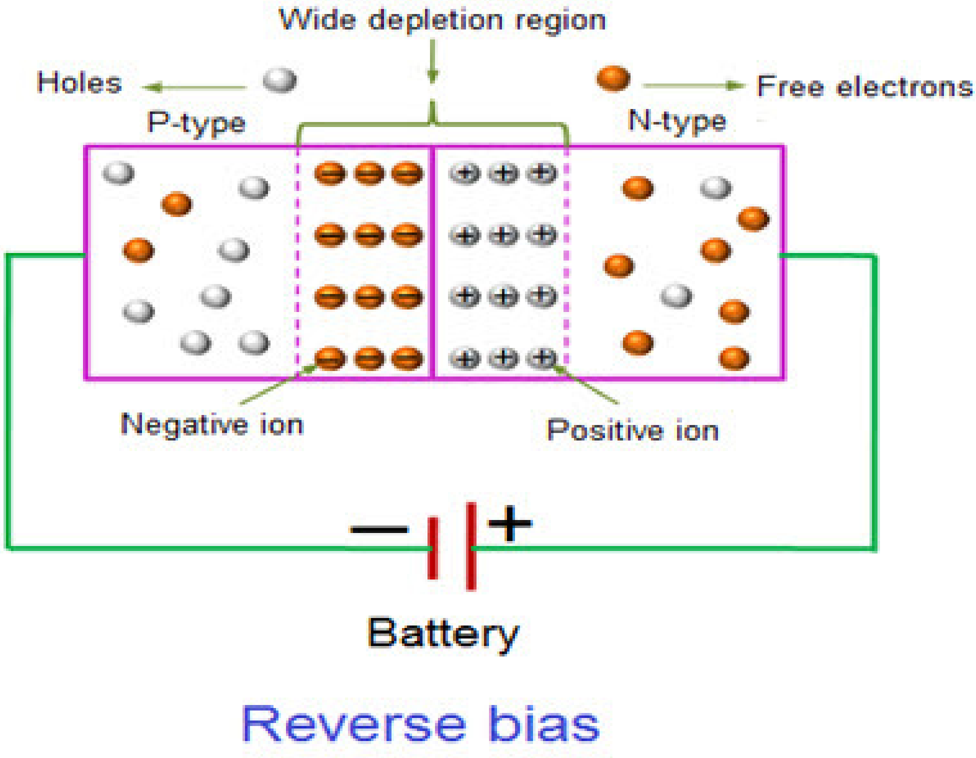


Figure 2: Reverse bias diode.

Rectifier for half-waves: Rectifying the AC voltage into a DC power source is one of the diode's most often used applications. Since a diode can only conduct current in one direction, there won't be any current if the input signal is negative.

Full wave Rectifier: Four diodes are used to create a full-wave rectifier diode circuit, which allows us to make both wave halves positive. There is a forward channel across the diode bridge for input cycles that are both positive and negative shows in Figure 3. Two of the diodes are forward biased, while the other two are reverse biased and are therefore essentially taken out of the circuit. Full-wave rectification is achieved when current flows through the load resistor in the same direction along both conduction channels.

In power supply, full-wave rectifiers are used to convert AC voltages into DC voltages. The ripple from the rectification process is decreased by connecting a large capacitor in parallel with the output load resistor.

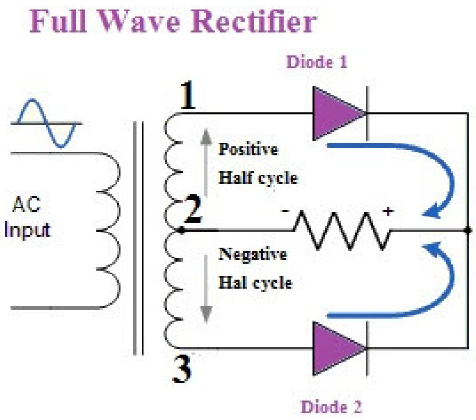


Figure 3: Full wave rectifier.

DISCUSSION

Single-phase Diode Rectifiers: Single-phase half-wave rectifiers and single-phase full-wave rectifiers are the two varieties of single-phase diode rectifiers that change a single-phase ac supply into a dc voltage. The functions of these rectifier circuits are discussed in the subsections that follow, and their results are summarised for comparison and analysis. The diodes are regarded as perfect because, for simplicity's sake, they have no forward voltage drop and no reverse recovery time. This presumption is often true for diode rectifiers that utilise the mains as their input, a low-frequency source, and when the forward voltage drop is minimal relative to the mains' peak voltage. Furthermore, it is believed that the load is entirely resistive because of the identical waveforms of the load voltage and load current. The effects of inductive load and capacitive load on a diode rectifier are thoroughly discussed in Section 10.5, Filtering Systems in Rectifiers [5], [6].

Single-phase Half-wave Rectifiers: The single-phase half-wave rectifier is the most basic type of single-phase diode rectifier. Figure 4 depicts a single-phase half-wave rectifier with a resistive load. One diode makes up the entire circuit, which is often powered by a secondary transformer as indicated. Diode D conducts during the positive half-cycle of the secondary voltage of the transformer. Diode D ceases conducting during the negative half-cycle. The voltage and current waveforms of the resistive load R and the voltage waveform of the diode D are presented in Fig. 4, assuming that the transformer has zero internal resistance and delivers perfect sinusoidal voltage on its secondary winding.

The peak inverse voltage (PIV) of diode D is equal to Vm during the negative half-cycle of the transformer secondary voltage, as can be seen by looking at the voltage waveform of diode D in Fig. 4. To prevent reverse breakdown, diode D's peak repetitive reverse voltage (VRRM) rating must be higher than Vm. In practise, the peak repetitive forward current (IFRM) rating of diode D must be chosen to be higher than the peak load current, Vm = R, since the forward current of diode D is equivalent to the load current in the positive half-cycle of the transformer secondary voltage. The transformer must also carry a dc current, which might cause the transformer core to become saturated with dc.

Single-phase Full-wave Rectifiers: Full-wave rectifiers with center-tapped transformers and bridge rectifiers are the two different forms of single-phase full-wave rectifiers. Figure 4 depicts a full-wave rectifier with a center-tapped transformer. It is obvious that each diode functions as a half-wave rectifier together with the corresponding half of the transformer. In order to achieve full-wave rectification in the load, the outputs of the two half-wave rectifiers are merged. The two halfwave rectifiers' dc currents are equal and opposing with respect to the transformer, thus there is no dc current to cause an issue with the saturation of the transformer core.

Figure 4 displays the voltage and current waveforms of the full-wave rectifier. It is evident from looking at the diode voltage waveforms vD1 and vD2 in Figure 5 that the PIV of the diodes is equal to 2Vm when they are in their blocking condition. In order to prevent reverse breakdown, the diodes' VRRM rating must be higher than 2Vm. (Note that the full-wave rectifier has twice the dc output voltage as compared to the half-wave rectifier in Figure 4.) Because each diode has a forward current equal to the load current while it is in the conducting state, the IFRM rating of these diodes must be chosen in practise to be higher than the peak load current, Vm = R.

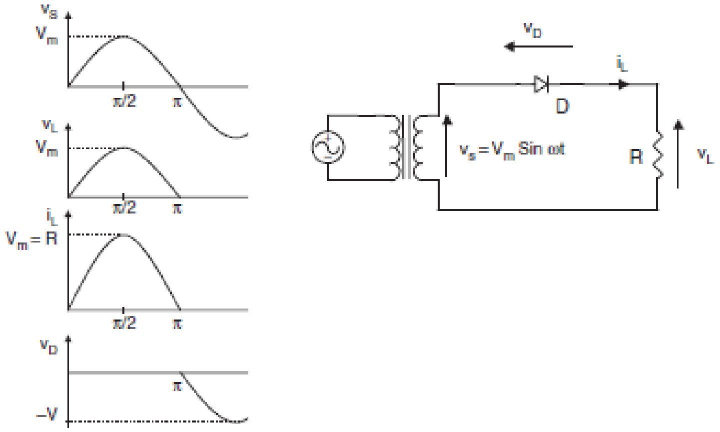


Figure 4: Single phase Half-wave Rectifier with resistive load and waveform.

A bridge rectifier like the one in Figure 5 can achieve full-wave rectification without a center-tapped transformer by utilising four diodes as opposed to two. Diodes D1 and D2 are the conduits via which the current travels to the load during the positive halfcycle of the secondary voltage of the transformer. D3 and D4 conduct in the negative halfcycle. Fig.5 displays the bridge rectifier's voltage and current waveforms. The utilised diodes' IFRM rating must, like that of the fullwave rectifier with center-tapped transformer, be higher than the peak load current, Vm = R. While in their blocking condition, the diodes' PIV decreases from 2Vm to Vm.

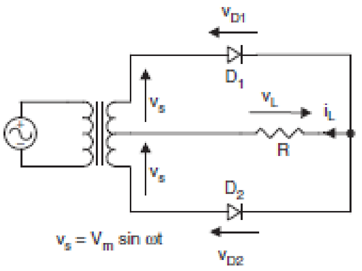


Figure 5: (a) Full-wave rectifier with center-tapped transformer.

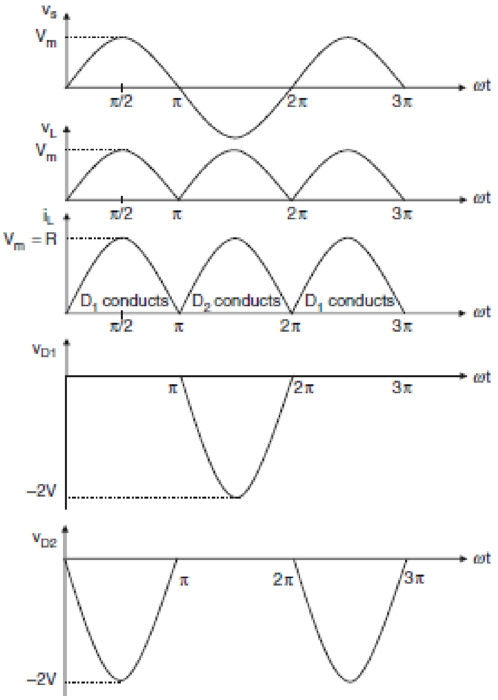
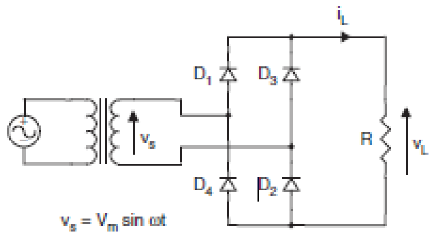


Figure 5: (b) Voltage and current waveforms of the full-wave rectifier with center-tapped transformer.



(c)

Figure 5: (c) Bridge rectifier.

Harmonics: In resistive load full-wave rectifier circuits, harmonic currents do not flow through the transformers. Harmonic currents are produced in half-wave rectifiers. Lists the harmonic current amplitudes of a half-wave rectifier with a resistive load in relation to the fundamental. In resistive loaded rectifier circuits, the additional loss brought on by harmonics is frequently disregarded since it is not significant in comparison to other losses. Harmonics, however, can result in significant loss and other issues including low power factor and interference with non-linear loads [7]–[9].

CONCLUSION

In electrical equipment that require DC power, diode rectifiers are a crucial component. Half-wave rectifiers are straightforward and reasonably priced, although they are inefficient and give out a pulsing DC output. Full-wave rectifiers require a center-tapped transformer but give a smoother DC output. The most effective rectifiers are bridge rectifiers, which may generate a high-quality DC output without the need for a center-tapped transformer. The choice of rectifier relies on the particular application and needs. Each form of rectifier has benefits and drawbacks. Diode rectifiers are a common component of many different electronic devices, and their significance in contemporary electronics cannot be emphasised.

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CHAPTER 8

A BRIEF DISCUSSION ON THREE-PHASE RECTIFIER

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ABSTRACT:

An electrical device is used a three-phase rectifier transforms three-phase AC electricity into DC power. A high-power DC supply is frequently needed in industrial applications, which is where this sort of rectifier is frequently utilised. Six diodes, placed in a precise arrangement to enable the conversion of each phase of the AC supply to DC, are used in the rectification process. An overview of the three-phase rectifier, its workings, and its uses are given in this chapter.

KEYWORDS:

AC Power, Diodes, DC Power, Industrial Application, Three-Phase Rectifiers.

INTRODUCTION

An electrical device is used a three-phase rectifier to change three-phase AC power into DC power. When large power levels are needed for industrial applications, three-phase AC power is frequently employed. Six diodes, placed in a precise arrangement to enable the conversion of each phase of the AC supply to DC, are used in the rectification process. A consistent and continuous output can be produced by further regulating the resultant DC voltage [1]–[3]. Applications including power supply for electric motors, welding equipment, battery chargers, and electrolysis frequently make use of three-phase rectifiers. They are also utilised in a number of other industrial equipment kinds, including pumps, compressors, and HVAC systems. High efficiency, dependability, and the capacity to deliver a steady and consistent DC output are the key benefits of employing a three-phase rectifier. The correction procedure is straightforward and needs little upkeep. Due to their great power handling capacity, three-phase rectifiers are appropriate for a variety of industrial applications. Overall, the three-phase rectifier is a crucial part of contemporary industrial applications because it offers a dependable and effective way to transform three-phase AC power to DC power.

For a given dc output power, single-phase diode rectifiers demand a rather high transformer VA rating. These rectifiers are therefore only appropriate for low to medium power applications. Three-phase or poly-phase diode rectifiers should be used for power outputs more than 15kW. Star rectifiers and bridge rectifiers are the two varieties of three-phase diode rectifiers that change a three-phase ac supply into a dc voltage. The processes of these rectifiers are explored, and their results are analysed and contrasted in tabular form, in the subsections that follow. For the purpose of simplicity, the transformers and the diodes are taken to be perfect, meaning that the transformers have no resistance and no leakage inductance and the diodes have no forward voltage drop or reverse current. In addition, it is assumed that the load is entirely resistive and that the waveforms of the load voltage and the load current are identical [4]–[6].

An electrical device is used a three-phase rectifier to change three-phase AC power into DC power. Six diodes are used in a precise configuration throughout the rectification process to enable the conversion of each AC supply phase to DC. A three-phase rectifier functions as follows, in greater detail:

1. **Three-phase AC power input:** The rectifier's input is three-phase AC power. Depending on the application, it normally has a voltage of 208 V, 220 V, 440 V, or 480 V. The rectifier makes use of six diodes, semiconductor components that only let electricity to flow in one direction. To enable the conversion of each phase of the AC supply to DC, these diodes are placed in a certain arrangement, often in a bridge configuration.
2. **Rectification Procedure:**Two of the diodes (D1 and D3) become forward-biased and permit current to flow through them during the positive half-cycle of the AC input voltage, while the remaining diodes (D2, D4, D5, and D6) become reverse-biased and do not conduct.
3. **Filtering:** The rectifier's output is a pulsing DC voltage with some residual AC components. A filtering circuit is often employed to eliminate these AC components and smooth the DC output. A capacitor and a resistor are used in this circuit to generate a smooth DC voltage by jointly filtering out the AC components.
4. **DC Output:**The rectifier's ultimate output is a steady, constant DC voltage. A variety of voltage regulators, including linear regulators, switching regulators, and pulse-width modulation (PWM) controllers, can be used to further adjust this value.

A single phase rectifier employs a single phase of a transformer's secondary coil to convert an AC supply to a DC supply, which is known as rectifying. Additionally, the diodes are linked to the single phase transformer's secondary winding. High ripple factor is this arrangement's disadvantage.

The ripple factor for a half wave rectifier is 1.21, whereas the ripple factor for a full wave rectifier is 0.482. The importance of the ripple element cannot be disregarded in any situation. While the value is fairly huge in the case of a half-wave rectifier, it is also quite large in a full-wave rectifier.

Therefore, a smoothing circuit is required in these arrangements in order to eliminate these ripples. The DC voltage's AC components are represented by these waves. The term for this is pulsing DC voltage. When this pulsing DC voltage is employed in several applications, the gadget performs poorly.

As a result, the rectifier system uses the smoothing circuit, which the filter acts as. However, the rectifier voltage eventually drops to zero following this blending process. Therefore, the ripple factor can be substantially decreased if a three phase transformer is used in place of a single phase transformer. One notable benefit of a three-phase transformer is that even without a smoothing mechanism, the rectified voltage does not fall to zero.

DISCUSSION

Three Phase Half Wave Rectifier: A particular kind of rectifier that transforms three-phase AC power into a pulsing DC output is known as a three-phase half-wave rectifier in Figure 1. The positive half-cycles of each phase are rectified using three diodes, one for each phase of the AC input. The operation of a three-phase half-wave rectifier is described in further detail below:

1. **Three-phase AC power input:**The rectifier's input is three-phase AC power. Depending on the application, it normally has a voltage of 208 V, 220 V, 440 V, or 480 V. For each phase of the AC input, the rectifier utilises one of three diodes. The diode conducts and becomes forward-biased during the positive half-cycle of each phase, allowing current to pass through it [7]–[9].
2. **Rectification Procedure:**The associated diode becomes forward-biased and conducts during the positive half-cycle of each phase, enabling current to pass through it. The other two diodes do not conduct and continue to be reverse-biased.
3. **Filtering:** The rectifier's output is a pulsing DC voltage with some residual AC components. A filtering circuit is often employed to eliminate these AC components and smooth the DC output. A capacitor and a resistor are used in this circuit to generate a smooth DC voltage by jointly filtering out the AC components.
4. **DC Output:**The rectifier's ultimate output is a pulsing DC voltage with a frequency that is three times that of the input AC frequency. The AC input voltage peak multiplied by the square root of three (1.732) gives the peak DC voltage value.

A straightforward and inexpensive rectification method that works well for low power applications is the three-phase half-wave rectifier. It does have certain drawbacks, though, such a low output voltage and a large ripple factor. As a result, it is often utilised in applications that require a low voltage DC supply and can withstand ripple.

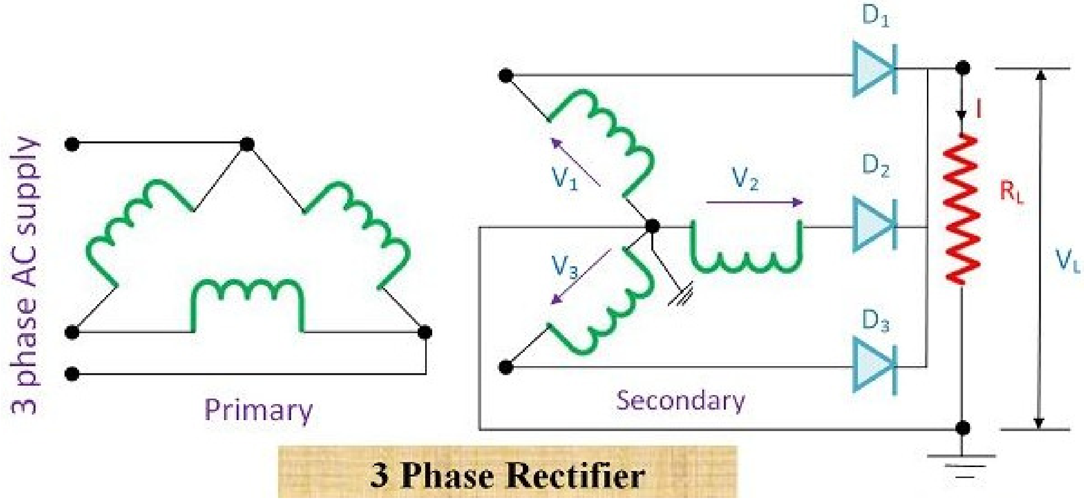

Figure 1: Three phase half wave rectifier (electronics coach).

Three diodes are connected to each of the three phases of the transformer's secondary winding in a three phase half wave rectifier. It is also known as Star Connected Secondary because the three secondary phases are connected in the shape of a star.

The secondary winding of the transformer is linked to the anode terminal of the diode. Additionally, the neutral point on the transformer serves as the connection between the three transformer phases.

This earthed neutral point serves as the load's negative terminal. One-third of the AC cycle is conducted by each diode, leaving the other two diodes open circuit. The output DC voltage will range from the supply voltage's highest value to 50% of the supply voltage.The Input and output voltage waveform of three phase half wave rectifier is shown in Figure 2.

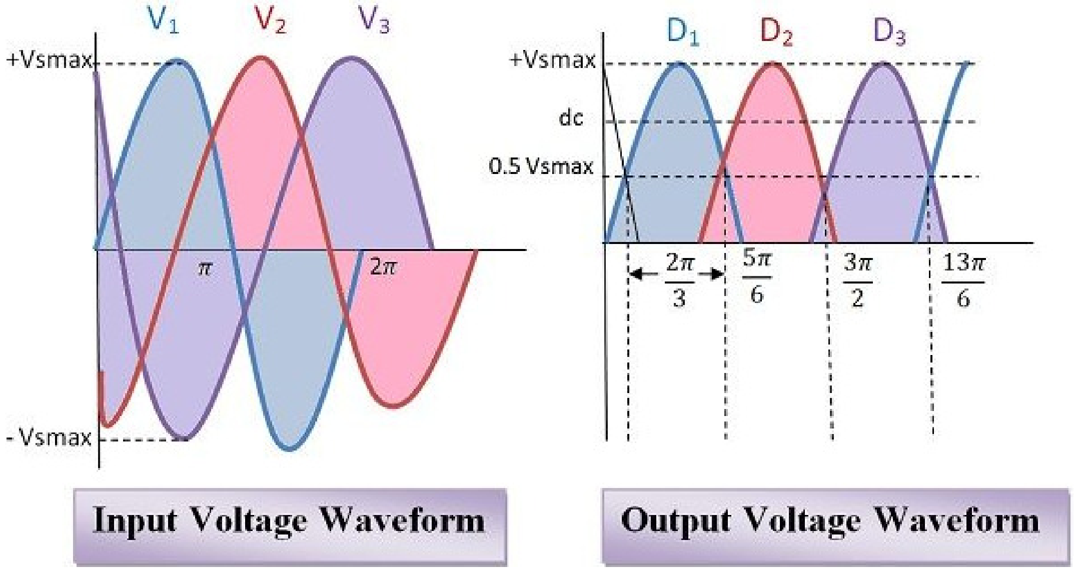

Figure 2: Input and output voltage waveform of three phase half wave rectifier (electronics coach).

The ripple factor for 3 phase half wave rectifier is derived in the equations below.

$$V_{dc} = \frac{1}{2\pi/3}\int_{\pi/6}^{5\pi/6} v \, d(\omega t) = \frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} V_{smax} \, Sin \, \omega t \, (dt)$$

$$= \frac{3 \, V_{s\,max}}{2\pi}[-\cos \omega t]_{\pi/6}^{5\pi/6}$$

$$= \frac{3 \, V_{s\,max}}{2\pi} \times 2 \times 0.866$$

$$V_{dc} = 0.827 \, V_{smax} \text{ or } 0.827 \times \sqrt{2} \, V_{s\,rms} \text{ i.e., } 1.17 \, V_{s\,rms}$$

$$I_{dc} = \frac{V_{dc}}{R_L} = \frac{0.827 \, V_{s\,max}}{R_L}$$

Now, we can derive the RMS value of the load current from the equation given below:-

$$I_{rms}^2 = \frac{1}{2\pi/3}\int_{\pi/6}^{5\pi/6} i^2 \, \mathrm{d}\,(\omega t) = \frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} I_{max}^2 Sin^2 \, \omega t \, (d\omega t)$$

$$= \frac{3}{2\pi}\int_{\pi/6}^{5\pi/6} \frac{V_{s\,max}^2}{R_L^2} Sin^2 \, \omega t \, (d\omega t)$$

$$= \frac{0.7V_{smax}^2}{R_L^2}$$

$$\text{Or } I_{rms} = \sqrt{\frac{0.7V_{smax}^2}{R_L^2}} = \frac{0.838 \, V_{smax}}{R_L}$$

$$\textit{Ripple factor, } \gamma = \sqrt{\frac{I_{rms}^2}{I_{dc}^2} - 1} = \sqrt{(\frac{0.838}{0.827})^2 - 1} = 0.17 \text{ or } 17\%$$

It is clear from the calculations above that the 3 phase half wave rectifier's ripple factor is 0.17, or 17%. The ripple factor for a single phase half wave rectifier is 1.21, whereas for a single phase full wave rectifier it is 0.482. Therefore, it is clear that a 3 phase rectifier has a far lower ripple factor value than a single phase rectifier. Additionally, the three phase rectifier has very high frequency ripples. As a result, these waves may be readily filtered as a result. In the case of three phase rectifiers, the ripple frequency is three times the supply frequency. Because of this, smoothing is simpler when using a three-phase rectifier than a single-phase rectifier.

Three phase full-wave Rectifier: Six diodes are utilised in a three phase full wave rectifier. The 6-diode half wave rectifier is another name for it. Each diode in this operates for one-sixth of the AC cycle. In three phase full wave rectifiers (inFigure 3), the output DC voltage variations are reduced. The output voltage varies between 86.6% of the maximum voltage and the peak voltage's highest value, or Vsmax. The output voltage of three phase full wave rectifiers is controlled and does not go to zero, which is a benefit. Between 86.6% of the maximum voltage and the voltage peak, the output voltage is kept constant. As a result, it seems controlled.

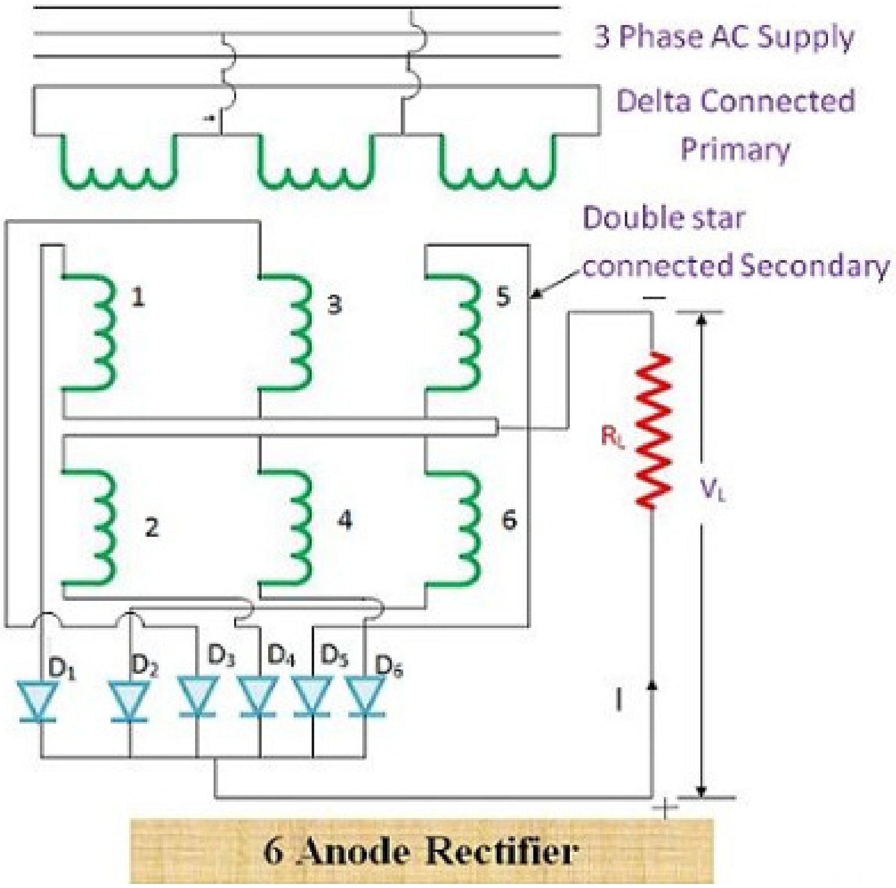

Figure 3: Three phase full-wave Rectifier (electronics coach).

The extensive use of diodes is the primary cause of the low output voltage fluctuation. Six diodes are the right number to utilise. This is because using more than six diodes raises the circuit's cost. Additionally, when the complexity of the circuit grows, the output voltage regulation won't change significantly.The Input and output voltage waveform of three phase full wave rectifier is shown in Figure 4.

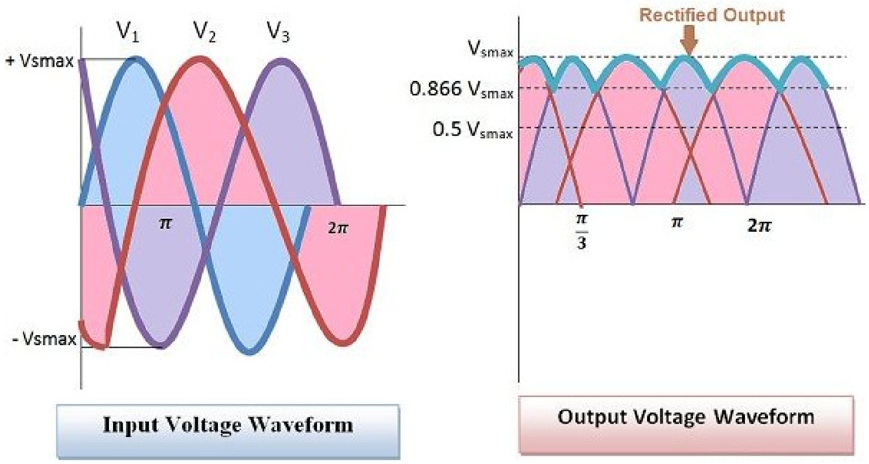

Figure 4: Input and output voltage waveform of three phase full wave rectifier (electronics coach).

Three Phase Bridge Rectifier: Due to the fact that bridge rectifiers don't require a centre tap transformer, this layout type is quite popular. The use of bridge rectifiers has the benefit of having a load current that is 0.95 times greater than the peak current via a diode. Through the secondary winding of the transformer in a three phase half eave rectifier (in Figure 5), the Vdc is around 2.34 times the rms value of the AC voltage. In a three-phase bridge rectifier, only one-third of the current passing through the load is carried by each diode.

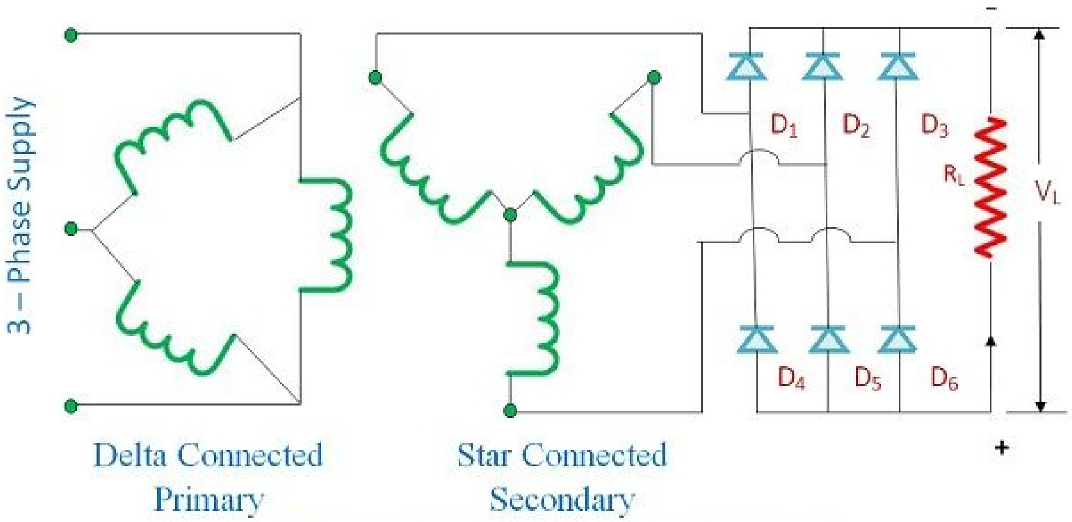

Figure 5: Three phase bridge Rectifier (electronics coach).

Therefore, in many situations, this form of bridge configuration is recommended. They are employed to fix the problems with single-phase rectifiers. Single-phase rectifiers have a large ripple factor and considerable output fluctuation, as we've already explained. Three phase transformers were developed to address this problem.

Application of Three phase rectifier: In order to convert three-phase AC power into DC power, three-phase rectifiers are frequently employed in electrical power systems. Three-phase rectifiers are mostly used in:

1. **DC power supplies:** To give DC power to different electronic devices including computers, servers, telecommunications equipment, and industrial machinery, power supplies employ three-phase rectifiers.
2. **Industrial Automation:**Three-phase rectifiers are frequently used in systems for motor drives, battery charging, welding, and electroplating, among other industrial automation applications.
3. **Renewable Energy Systems:**In order to convert the AC electricity generated by these systems into DC power that can be utilised to power homes and businesses, three-phase rectifiers are also employed in renewable energy systems like wind turbines and solar power systems.
4. **Railway Traction Systems:**In order to transform the three-phase AC power from the overhead lines into the DC power needed to run the trains, three-phase rectifiers are employed in railway traction systems.
5. **Electrochemical Operations:**Three-phase rectifiers are used to convert AC power into the DC power needed for electrochemical processes including electrolysis, electroplating, and electro-refining.

Overall, three-phase rectifiers play a significant role in converting AC power into DC power for a variety of applications and are essential parts of many electrical power systems.

Advantage of three phase rectifiers:

1. **Higher Efficiency:** Because three-phase rectifiers provide an output that is smoother and has fewer ripples than single-phase rectifiers, they are more efficient. Because of this, they are better suited for high-power applications.
2. **Superior Voltage Control:**Three-phase rectifiers provide superior voltage control since their DC output voltage remains constant despite changes in the input voltage.
3. **Higher Power Output:** Compared to single-phase rectifiers, three-phase rectifiers have a higher power output. Because of this, they are appropriate for industrial uses where high power levels are needed.
4. **Cost-Effectiveness:** Because three-phase rectifiers use fewer components and are more efficient than single-phase rectifiers, they are more economical.
5. **Reduced Harmonic Distortion:** Three-phase rectifiers are better suited for applications that call for high-quality power because they create less harmonic distortion than single-phase rectifiers.

Disadvantage of three phase rectifiers:

1. **Higher Complexity:** Three-phase rectifiers are more complex than single-phase rectifiers as they require three sets of diodes to rectify the three-phase AC input.
2. **Higher Installation Cost:** Three-phase rectifiers require three-phase power input, which may require a higher installation cost for three-phase power supply lines and transformers.
3. **Limited Compatibility:** Three-phase rectifiers are not compatible with single-phase power supply lines. This limits their use in applications that only have access to single-phase power.
4. **Higher Maintenance Cost:** Three-phase rectifiers have more components and are more complex, which may result in a higher maintenance cost.
5. **Limited Voltage Regulation Range:** Three-phase rectifiers have a limited voltage regulation range, which may not be suitable for applications that require a wide range of voltage regulation [10], [11].

CONCLUSION

The three-phase rectifier is a crucial part of contemporary industrial applications, to sum up. It offers a dependable and effective way to change three-phase AC electricity into DC power. Six diodes are positioned in a specified arrangement throughout the rectification process to enable the conversion of each phase of the AC supply to DC. The rectifier's DC output may be further controlled to deliver a steady and consistent voltage for a variety of applications. Many industrial power supply demands have found a dependable and affordable answer in the three-phase rectifier.

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CHAPTER 9

A STUDY ON DC–DC CONVERTER

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ABSTRACT:

Electronic devices used DC-DC converters to change the DC voltage level. They are often employed in many different applications, including electric cars, battery chargers, and power supply. Switching methods are used by DC-DC converters to provide high efficiency and voltage control. An overview of the fundamental concepts governing DC-DC converters, including kinds, topologies, and applications, is given in this chapter.

KEYWORDS:

DC Voltage, DC Chopper, DC-DC Converter, Voltage Regulation, Switching Techniques.

INTRODUCTION

Electricity that travels in one direction with a constant voltage level is known as direct current (DC). Electronic equipment, motors, and batteries are just a few of the many applications where DC power is utilised. However, varying voltage levels from a few volts to several hundred volts—are needed for various devices and applications. Electronic devices called DC-DC converters offer a way to quickly change one DC voltage level to another. Many sectors, including telecommunications, aerospace, automotive, and renewable energy, make extensive use of DC-DC converters. They are utilised in several applications, including electric cars, battery chargers, and power supply. Switching methods are used by DC-DC converters to provide high efficiency and voltage control. They work by rapidly turning on and off a voltage source to provide an output voltage that differs from the input value [1], [2].

Electronics as a field has undergone a revolution because to the advent of DC-DC converters, which have made it possible to build smaller, more effective, and more dependable gadgets. The efficiency and performance of DC-DC converters have dramatically increased while their size, weight, and price have significantly decreased thanks to technological improvements. They are now a necessary component in many applications, including those that call for high reliability, low noise, and high power density. In this chapter, we'll give a general introduction of DC-DC converter fundamentals, including their kinds, topologies, and uses. We will go through the benefits and drawbacks of several DC-DC converter topologies and give examples of how they are used in different applications. Finally, we will discuss some of the most recent developments in DC-DC converter research and development.

Power sources for modern electronic systems must be of the highest calibre, compact, lightweight, dependable, and effective. Efficiency is lacking in linear power regulators, whose working theory is based on a voltage or current divider. They can only produce voltages that are lower than the input voltage. Additionally, they have a poor power density due to the need for low-frequency (50 or 60 Hz) line transformers and filters. However, linear regulators are capable of producing a very high-quality output voltage. Their primary use is as low drop-out voltage (LDO) regulators at low power levels. In linear regulators, electronic components function in their active (linear) modes. Switching regulators are utilised when power levels are greater. Switching regulators operate in on- and off-states with power electronic semiconductor switches. Switching regulators can achieve high energy conversion efficiencies because there is no power loss in certain conditions (low voltage across a switch in the on state, zero current through a switch in the off state). High frequency operation is possible with modern power electronic switches. Transformers, filter inductors, and capacitors all become smaller and lighter as working frequency rises. Additionally, converters' dynamic properties get better as operating frequencies go up. The corner frequency of the output filter typically determines the control loop's bandwidth. As a result, high operating frequencies make it possible to achieve a quicker dynamic reaction to sudden changes in the input voltage or load current.

Dc-dc power conversion employs high-frequency electronic power processors. Dc-dc converters have the following functions: converting a dc input voltage VS into a dc output voltage VO; regulating the dc output voltage against load and line variations; lowering the ac voltage ripple on the dc output voltage below the required level; providing isolation between the input source and the load (isolation is not always required); protecting the supplied system and the input source from electromagnetic interference (EMI); and satisfying regulatory requirements. Pulse width modulated (PWM) converters with hard switching and resonant and soft switching are the two primary categories of dc-dc converters. The first category of dc-dc converters is covered in this chapter. The last three decades have seen a huge increase in the use of PWM converters. At all power levels, they are commonly utilised. PWM converter topologies and characteristics are widely known and extensively discussed in the literature.

Low component count, high efficiency, constant frequency operation, relatively easy control, commercial availability of integrated circuit controllers, and capability to achieve high conversion ratios for both step-down and step-up application are all benefits of PWM converters. PWM dc-dc converters have the drawback that their rectangular voltage and current waveforms result in semiconductor device turn-on and turn-off losses, limiting their useful operating frequencies to the megahertz range. Additionally, rectangular waveforms naturally produce EMI.

Isolated and non-isolated DC-DC converters can be generically categorised into two categories. DC-DC converters with electrical isolation between the input and output circuits are known as isolated DC-DC converters. To transmit electricity from the input to the output circuit, they employ a transformer, which helps to lower noise, increase safety, and provide better voltage regulation. High-voltage applications including power supply for industrial equipment, renewable energy sources, and electric cars frequently employ isolated DC-DC converters. Fly back, forward, push-pull, and half-bridge converters are a few examples of isolated DC-DC converters [3], [4].

DC-DC converters that are not electrically separated between the input and output circuits are known as non-isolated DC-DC converters. They transmit electricity from the input to the output circuit using electrical components like inductors and capacitors. Low-voltage applications including battery-powered gadgets, mobile phones, and consumer electronics frequently employ non-isolated DC-DC converters. Buck, boost, buck-boost, and SEPIC (Single-Ended Primary Inductor Converter) converters are examples of non-isolated DC-DC converters. Depending on the needs of the particular application, isolated and non-isolated DC-DC converters each have their own benefits and drawbacks. It is crucial to select the right kind of DC-DC converter based on requirements for voltage and current, efficiency, cost, and size.

DISCUSSION

DC Choppers:A DC chopper is an electrical circuit that changes a fixed DC voltage into a variable DC voltage. It is also known as a DC-to-DC converter or a voltage converter (shown in figure 1). In a variety of applications, including motor speed control, voltage regulation, and renewable energy systems, it is a form of power electronics circuit that enables the control of DC voltage levels.

A DC chopper works by rapidly turning a DC voltage on and off using a switch (such a transistor or MOSFET), followed by filtering the resultant waveform to produce the required output value. The switch's duty cycle may be changed to adjust the average output voltage. High-frequency harmonics are produced as a result of the DC chopper's high-frequency switching, and these harmonics might result in EMI and other issues. The output waveform is often filtered using an inductor and a capacitor to reduce these effects. Based on their working modes, DC choppers may be divided into numerous varieties, including step-up, step-down, and step-up/down choppers. Step-up choppers are used to raise the level of DC voltage, whilst step-down choppers are used to lower the level of DC voltage. The DC voltage level is increased and decreased using step-up/down choppers. Due to its great efficiency, capacity to handle high power levels, and ability to manage DC voltage levels, DC choppers are generally utilised in power electronics applications [5], [6].

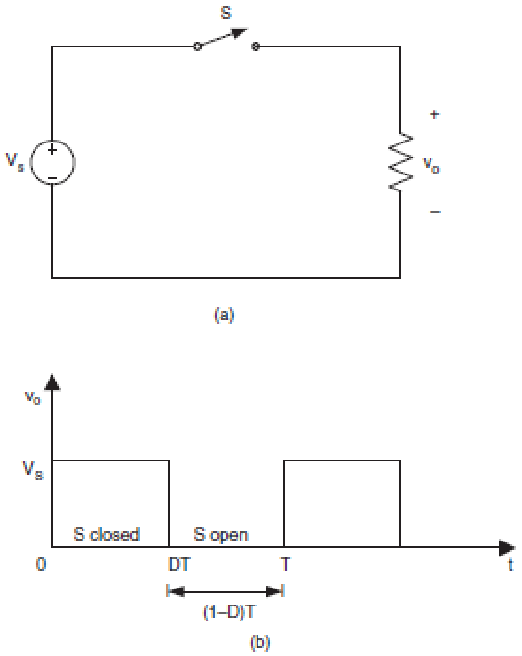

Figure 1: DC chopper with resistive load(a) circuit diagram and (b) output voltage waveform.

Figure1 (a) depicts a step-down dc chopper with a resistive load. A dc input voltage source (VS), a programmable switch (S), and a load resistance (R) are connected in series. Switch S typically has the ability to block voltage in one direction and conduct current in one way. Power MOSFETs, IGBTs, MCTs, power BJTs, or GTOs are frequently used in the implementation of power electronic switches. When an antiparallel diode is utilised or included in a switch, the switch displays the feature of bidirectional current conduction. A step-down chopper's waveforms are shown in Figure 1(b). Duty ratio D, or the ratio of switch on time to the total of switch on and off periods, is being used to run the switch. For operating at a fixed frequency, and may be controlled by changing the duty ratio D. The converter gets its name from the fact that the average output voltage is always lower than the input voltage.

Commonly utilised in DC drives are step-down choppers.

As illustrated in Figure 2(a), the load in such a scenario is represented as a series combination of inductance L, resistance R, and back emf E. An antiparallel diode D needs to be connected across the load in order to provide a channel for a continuous inductor current flow when the switch is in the off state. A first-quadrant chopper is one that delivers a positive voltage and current to the load as shown in Figure.2 (a). Assuming that the load current never falls below zero and that the load time constant = L/R is significantly larger than the period T, the load voltage and current are graphed in Figure2 (b). By altering the duty ratio D, the average output voltage and current levels may be changed.

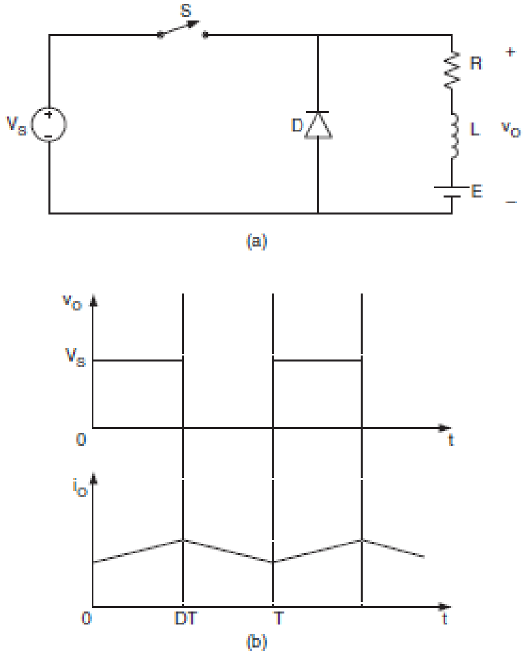

Figure 2: DC chopper with RLE load: (a) circuit diagram and (b) waveforms.

Types of Chopper: Based on their configuration and operating modes, DC choppers may be divided into many varieties. Here are some examples of popular DC helicopter types:The DC voltage level is decreased using a step-down (buck) chopper. The switch's duty cycle is less than 50%, and the output voltage is less than the input voltage.

1. **Step-Up (Boost) Chopper:** This kind of chopper is employed to raise the level of DC voltage. The switch's duty cycle is greater than 50%, and the output voltage is greater than the input voltage.
2. **Step-Up/Down (Buck-Boost) Chopper:** This kind of chopper has the ability to change the amount of DC voltage. Depending on the duty cycle of the switch, the output voltage may be either greater or lower than the input voltage.Similar to the step-down chopper, the forward chopper merely utilises an extra diode to restrict current flow to one direction.
3. **Reverse Chopper:** This kind of chopper is comparable to a step-up chopper, but it only allows current to travel in one direction by adding a second diode.

4. **Dual Chopper:** In this kind of chopper, two choppers are combined into one circuit. It may be used to manage the voltage in two distinct loads or to generate larger voltage gains.

5. **Multi-Level Chopper:** To provide significant voltage gains, this kind of chopper employs numerous switching levels. It may be utilised in high-power systems like electric cars and other energy sources.

The particular application and the necessary voltage level must be considered while choosing the chopper type. Each kind has benefits and drawbacks, and the design should take these things into account. A few examples are efficiency, cost, complexity, and dependability.

Applications of DC–DC Converters: The majority of step-down choppers' uses are in high-performance dc drive systems, such as electric traction, electric automobiles, and machine tools. High-quality armature currents are produced by the dc motors thanks to their mechanical inertia and winding inductances, which function as filters. Step-down choppers' average output voltage is a linear function of switch duty ratio. Step-up choppers are mostly utilised in ignition and radar systems. The DC choppers may be configured to operate in two or four quadrants. Two-quadrant helicopters might be a component of an autonomous power system that includes battery packs and renewable energy sources like solar arrays, fuel cells, or wind turbines. In drives where regenerative breaking of dc motors is desirable, such as transportation systems with frequent pauses, four-quadrant choppers are used. The inputs to the current-driven inverters are the dc choppers with inductive outputs.

PWM dc-dc converters are created by adding reactive component filtering to dc choppers. As dc transformers that supply dc voltage or current to the load at a different level than the input source, dc-dc converters can be thought of as such. Electronic switching mechanisms, as opposed to electromagnetic ones like those used in traditional transformers, are used to carry out this dc transition. Dc-dc converter output voltages can be as low as one volt for specialised VLSI circuits and as high as tens of kilovolts for X-ray lights. Modern microprocessors require an output voltage of 3.3V, whereas logic circuits require 5 and 12V, telecommunications equipment needs 48V, and aeroplanes' primary dc bus needs 270V. 48V, 170V (the peak value of a 120V rms line), and 270V are some common input voltages.

In addition to input/output voltages, which may be further changed with the turns ratio in isolated converters, power levels, voltage and current strains on semiconductor switches, and the use of magnetic components all play a role in determining the architecture of dc-dc converters. Popular in low power applications (up to 200W) is the low part-count fly back converter. The fly back transformer's huge core size and the semiconductor switch's high voltage stress are the primary drawbacks of this design. A single switch converter also exists in the forward converter. It is common in low/medium power applications (up to few hundred watts) because of its decreased core size requirements. The necessity to demagnetize the winding and the high voltage stress on the semiconductor switch are drawbacks of the forward converter. At medium power levels, the push-pull converter is also employed. The transformer's compact size is a result of bidirectional excitation. One benefit of a push-pull converter is the ability to ground the drive terminals of both switches, substantially simplifying the control circuitry. The push-pull converter's potential core saturation in an asymmetrical situation is a drawback.

Similar to push-pull converters, half-bridge converters are used in a variety of applications. In the half-bridge converter, transformer saturation is not a concern. However, to split the input dc source in half, two more input capacitors are needed. High power and voltage levels (up to several kilowatts) are employed with the full-bridge converter. Power switches are only subject to the input voltage source value's voltage stress. The full-bridge converter's large number of semiconductor components is a drawback.

The dc-dc converters are the fundamental components of distributed power supply systems, which convert a common dc bus voltage into a variety of different voltages in accordance with the needs of specific loads. These distributed DC systems are frequently found in space stations, ships, aircraft, and computer and telecom equipment. Variable supply voltages are anticipated to be used by contemporary portable wireless communication and signal processing devices to reduce power consumption and increase battery life. Synchronous rectification is used in these applications for low output voltage converters. Utility ac grid-related dc-dc converter applications make up a significant portion of the market. If the power grid goes down, there has to be a backup energy source, such a battery pack, for crucial loads.

Uninterruptible power supply (UPSs) of several varieties were developed in response to the requirement for continuous power delivery. The rectified grid voltage is adjusted to match the backup source's level using dc-dc converters in UPSs. Bidirectional dc-dc converters are frequently employed because, in normal operation, energy flows from the grid to the backup source, and, in emergency situations, the backup source must provide the load. The dc-dc converters are furthermore utilised by certain battery chargers.

Odd harmonics in power electronic loads, particularly those with front-end rectifiers, contaminate the ac grid. The dc-dc converters are employed as intermediary stages, immediately following a rectifier and before the dc-dc converter that supplies power to the load, for shaping the input ac current to enhance power factor and reduce harmonic content. Particularly common in these power factor correction (PFC) applications is the boost converter.

The use of dc-dc converters at the interfaces between ac networks and dc renewable energy sources like fuel cells and solar arrays is another utility grid-related application. With extra secondary transformer windings, several outputs are available in isolated dc-dc converters. A feedback loop regulates one output alone. The duty ratio of the output that is being controlled and its loads affect other outputs. A multiple-output DC-DC converter is a practical choice when one tightly regulated output voltage and one or more non-critical additional output voltage levels are required.

Advantages of DC–DC Converters: DC-DC converters, also known as DC choppers or voltage converters, have several advantages given below:

1. Voltage adjustment is possible with DC-DC converters even when the input voltage varies. This may be used to power electrical devices and control the voltage in renewable energy systems, among other things.
2. **Efficiency:** DC-DC converters can have a high efficiency, usually between 80 and 95 percent. As a consequence, batteries last longer and use less energy. Less power is also lost as heat.
3. **Flexibility:** DC-DC converters are capable of being built to work with a variety of input and output voltages, currents, and power levels. This qualifies them for a wide range of uses, including large-scale power systems and portable gadgets.
4. Electrical isolation between the input and output circuits is a feature that some DC-DC converters can offer, improving safety and lowering the possibility of electrical interference.

Disadvantages of DC–DC Converters:

1. **Complexity:** The design and implementation of DC-DC converters can be challenging and involve careful consideration of component choices, control strategies, and protective circuits. The system's cost and complexity may rise as a result.
2. **Electromagnetic interference (EMI):** High-frequency switching in DC-DC converters can produce EMI, which can impact surrounding electronic equipment and lead to reliability problems.
3. **Noise:** DC-DC converters may produce output voltage noise, which may impair the functionality of delicate electronic circuits.
4. **Dimensions:** Inductors, capacitors, and other parts that might take up a lot of space are needed for DC-DC converters. This could be a drawback for applications that need little space, such as portable devices.

In conclusion, DC-DC converters have numerous benefits, such as voltage control, high efficiency, and flexibility, but they also have certain drawbacks, including complexity, electromagnetic interference (EMI), and noise. The choice of a DC-DC converter is determined by the particular application and the trade-offs between complexity, cost, and performance [7]–[9].

CONCLUSION

In contemporary electronics, DC-DC converters are crucial components. They offer a way to effectively change DC voltage levels to accommodate various devices and applications. Technology developments have led to smaller, more effective, and more dependable DC-DC converters. Because of this, they are often used in many different industries, including as telecommunications, automobiles, and aircraft. The development of novel DC-DC converter topologies and techniques will continue to be an important field of research and innovation as the desire for improved efficiency and performance rises.

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CHAPTER 10

A BRIEF DISCUSSION ON VOLTAGE SOURCE INVERTER (VSI)

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ABSTRACT:

An electrical device is used a voltage source inverter (VSI) transforms DC voltage into AC voltage. The VSI has uses in a number of industries, including electric cars, motor drives, and alternative energy systems. The output voltage and current waveforms are greatly influenced by the VSI structure and control method. This study gives a general review of the VSI in this context, covering its architecture, control methods, and applications.

KEYWORDS:

AC Voltage, Control Techniques, DC Voltage, Voltage Source Inverter, VSI.

INTRODUCTION

Electronic devices is used inverters to change the voltage from DC (Direct Current) to AC (Alternating Current). They have a wide range of uses, including electric cars, motor drives, uninterruptible power supplies, and renewable energy systems. As the need for renewable energy and electric cars rises, inverters are becoming increasingly important in the modern power electronics sector. The power electronic circuit used in inverters is responsible for switching the DC voltage at high frequencies to create an AC voltage waveform. Depending on the needs of the application, the inverter can create an AC voltage waveform that is either sinusoidal or modified sine wave [1]–[3].

Based on the kind of output waveform they generate; inverters can be categorised. Square wave, modified sine wave, and pure sine wave inverters are the three types of inverters. The output waveform of square wave inverters is not ideal for the majority of applications. While still including some harmonic distortion, the waveform produced by modified sine wave inverters is closer to a pure sine wave. A smooth, consistent sinusoidal waveform is created by pure sine wave inverters that resembles the waveform generated by the grid. The precise needs of the application determine the type of inverter to use. For instance, pure sine wave inverters are more suited for sensitive electronic appliances and equipment, whereas modified sine wave inverters are better suited for applications like lights and tiny electronic gadgets.

Inverters can also be divided into groups according to the topology they employ. Voltage Source Inverters (VSI) and Current Source Inverters (CSI) are the two most popular types of inverters. While CSI utilises a DC current source and switches it at high frequencies to create an AC current waveform, VSI employs a DC voltage source to create an AC voltage waveform. Inverters are crucial components in the current power electronics sector, and their significance is developing quickly as a result of the rising need for renewable energy sources and electric cars. Based on the sort of topology they employ, inverters can generate a variety of output waveforms. The precise needs of the application determine the type of inverter to use.

Static power converters' main goal is to turn a dc power source into an ac output waveform. These waveforms are needed in a variety of applications, including voltage compensators, flexible ac transmission systems (FACTSs), active filters, static var compensators, uninterruptible power supply (UPSs), adjustable speed drives (ASDs) and UPSs.

The amplitude, frequency, and phase of sinusoidal ac outputs ought to be adjustable. These topologies can be categorised as voltage-source inverters (VSIs), where the independently regulated ac output is a voltage waveform, depending on the kind of ac output waveform. Because they naturally function as voltage sources as required by many industrial applications, such as ASDs, which are the most common usage of inverters, these architectures are the most extensively utilised.

Similar topologies may be seen in current-source inverters (CSIs), which have a current waveform as their independently regulated ac output. In medium-voltage industrial applications where top-notch voltage waveforms are needed, these structures are still often utilised.

Types of Inverter: Inverters come in a variety of varieties, and they may be categorised according to a number of criteria, including the types of input and output waveforms, the topologies employed, and the applications. Some of the most popular inverter types include the following:

1. **Square Wave Inverter:**The simplest sort of inverter is the square wave inverter, which generates an output waveform that is square and unsuitable for the majority of applications. In recent applications, this kind of inverter is uncommon.
2. **Modified sine Wave Inverter:**This device creates a waveform that is more resembling of a pure sine wave while yet including some harmonic distortion. The majority of electrical gadgets and devices can use this sort of inverter, although certain delicate equipment might not.
3. **Pure sine Wave Inverter:**A pure and reliable sinusoidal waveform, akin to the waveform generated by the grid, is created by a pure sine wave inverter. Appliances and sensitive electrical devices can use this kind of inverter.
4. **Grid-tie Inverter:**The grid-tie inverter is a component found in wind turbines and solar photovoltaic systems, two sources of renewable energy. This kind of inverter's purpose is to feed the extra energy generated by the renewable source back into the grid by synchronising the output voltage and frequency with it.
5. **Voltage Source Inverter (VSI):** To create an AC voltage waveform, the voltage source inverter changes a DC voltage source at high frequencies. Electric cars, motor drives, and uninterruptible power sources frequently employ this kind of inverter.
6. **Current Source Inverter (CSI):** To create an AC current waveform, the current source inverter changes a DC current source at high frequencies. Common high-power uses for this kind of inverter include electric drives and welding equipment.
7. **Multilevel Inverter:**To provide a high-quality output waveform with minimal harmonic distortion, the multilevel inverter changes several DC voltage sources at various levels. High-power applications like electric motors and renewable energy systems frequently employ this kind of converter.

Inverters come in a variety of varieties, and they may be categorised according to a number of criteria, including the kinds of input and output waveforms, the topologies employed, and the applications. The particular application requirements and the intended output waveform determine the type of inverter that should be used [4], [5].

DISCUSSION

Voltage source inverter: A voltage source inverter (VSI) transforms a DC voltage source into an AC voltage source with variable frequency and variable amplitude. By adjusting the switching signals applied to the inverter switches' amplitude and frequency, a VSI's output voltage may be adjusted. Electric cars, motor drives, and uninterruptible power supply are just a few examples of the many applications that VSI is employed in.

Four switches make up the basic architecture of a VSI, two of which are linked to the positive DC bus and the other two to the negative DC bus. To create an AC voltage waveform, the switches are activated in pairs. Depending on the needs of the application, the switching frequency is normally between 1 and 20 kHz, and the output voltage waveform can be either a square wave, a modified sine wave, or a pure sine wave. The single-phase and three-phase VSI topologies are the most often utilised VSI topologies. While three-phase VSIs are employed in high-power applications, single-phase VSIs are used in low-power ones.

A single-phase AC voltage waveform is produced by the complimentary operation of two switches that make up the single-phase VSI. By adjusting the duty cycle of the switching signals supplied to the switches, the output voltage waveform may be managed. Depending on the needs of the application, the output voltage waveform of a single-phase VSI can be a square wave, modified sine wave, or pure sine wave. Six switches make up the three-phase VSI, which produces a three-phase AC voltage waveform when they are operated in pairs. By adjusting the switching signals applied to the switches' amplitude and frequency, the output voltage waveform may be changed. In high-power applications like electric motors and renewable energy systems, the three-phase VSI is frequently employed.

High efficiency, rapid reaction times, and precise control of the output voltage and frequency are all benefits of VSI. High harmonic distortion, which can be problematic in particular applications like motor drives and renewable energy systems, is one drawback of VSI. In conclusion, a voltage source inverter (VSI) is a type of inverter that changes a DC voltage source into an AC voltage source with a variable frequency and variable amplitude. Electric cars, motor drives, and uninterruptible power supply are just a few examples of the many applications that VSI is employed in. Depending on the needs of the application, the output voltage waveform of a VSI can be a square wave, modified sine wave, or pure sine wave. Although VSI has quick reaction times, precise control over output voltage and frequency, and excellent efficiency, it can have substantial harmonic distortion, which can be problematic in particular applications [6]–[8].

Single phase voltage source inverter: The inverter, sometimes referred to as a dc-ac converter, transforms dc power into ac power at a desired output voltage and frequency. The battery, fuel cell, solar array, magneto hydrodynamic generator, or existing power supply network can all be used to provide the inverter with the dc power it needs to function. A constant dc link voltage is provided by the filter capacitor across the input terminals of the inverter. As a result, the inverter is a voltage source with changeable frequency. A dclink converter is a combination of an ac to dc converter and a dc to ac inverter. The two main categories of inverters are voltage source and current source inverters. An inverter when the dc source has a low or insignificant impedance is known as a voltage-fed inverter (VFI) or, more broadly, a voltage-source inverter (VSI). At the input terminals, the voltage remains constant. A high impedance, continuous dc source is used to supply an adjustable current to a current-source inverter (CSI).

While VSIs constructed of GTOs, power transistors, power MOSFETs, or IGBTs use self-commutation with base or gate drive signals for their controlled turn-on and turn-off, a voltage source inverter that uses thyristors as switches requires some sort of forced commutation. Both a halfbridge and a full bridge arrangement are possible for a typical single-phase voltage or current source inverter. Three-phase or multiphase topologies can be created by connecting the single-phase components. Induction heating, standby aviation power supply, UPS (uninterruptible power supplies) for computers, HVDC transmission lines, and other industrial applications are a few examples of where inverters are used.

Voltage Control in Single - Phase Inverters: The battery or rectifier supplies the dc supply to the inverter according to the inverter system diagram in Figure 1. The size and frequency of the ac output voltage's fundamental voltage are controlled by the inverter. When inverters are used to provide AC loads, which may need a constant or changeable voltage at their input terminals, it is crucial that the inverters' output voltage be precisely adjusted to meet the loads' needs. The voltage to frequency ratio at the inverter output terminals, for instance, must be maintained constant if the inverter powers a magnetic circuit like an induction motor. This prevents saturation in the inverter-fed device's magnetic circuit. The many approaches to controlling the output voltage of inverters may be divided into three categories: (a) external control of ac output voltage (b) external control of dc input voltage (c) internal control of the inverter.

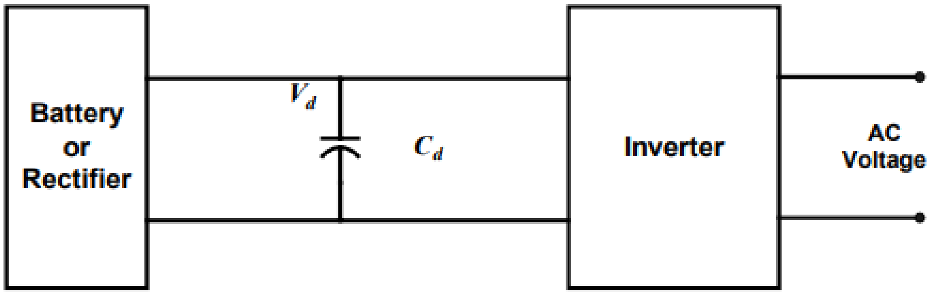

Figure 1: Schematic for Inverter System (tntech).

The third approach does not require any external components, unlike the other two ways which do. The third form of control is covered in considerable length in the next section since it is mostly concerned with the internal control of the inverters.

Pulse Width Modulation Control: An inverter's internal control mechanisms can be used to exert control over the basic magnitude of the output voltage, eliminating the need for additional control electronics. Using the inverter's Pulse Width Modulation (PWM) control is the most effective way to accomplish this. By altering the on and off durations of the inverter components, a controllable ac voltage may be produced in this method even if the inverter is fed by a set input voltage. The PWM control technique has the following benefits:

a) The output voltage control may be achieved without the inclusion of any additional components.
b) PWM reduces the higher order harmonics, whereas a filter can get rid of the lower order harmonics.

Although PWM is widely utilised in all industrial equipment, this scheme's downside is that the switching devices used in the inverter are costly since they must have quick turn-on and turn-off periods. PWM approaches are distinguished by pulses of constant amplitude and varying duty cycles for each period. To manage the inverter output voltage and lessen its harmonic content, these pulses' widths are adjusted. The allowable harmonic content in the inverter output voltage determines which PWM method should be used since different PWM approaches basically differ in the harmonic content of their respective output voltages.

Applications of single phase VSI: Low-power applications that need for a single-phase AC voltage source frequently employ single-phase voltage source inverters (VSIs). Single-phase VSI is used in the applications listed below:

1. Single-phase VSI is frequently employed in modest power AC motor drives for products like fans, pumps, and home appliances. The output voltage waveform may be altered to regulate the motor's variable speed and torque.
2. **Uninterruptible power supply (UPS):** To provide backup power in the event of a power outage, single-phase VSI is used in UPS systems. A consistent and dependable AC voltage source may be produced by controlling the output voltage waveform.
3. **Lighting systems:** Indoor and outdoor lighting systems, including streetlights, use single-phase VSI. The output voltage waveform may be adjusted to give lights brightness and dimming control.
4. Tiny-scale renewable energy systems, like as solar photovoltaic systems and tiny wind turbines, employ single-phase VSI. It is possible to manipulate the output voltage waveform to synchronise with the grid and feed any extra energy back into the grid.
5. **Medical Devices:**Single-phase VSI is used in X-ray and ultrasound machines, among other medical devices. To provide the machinery accurate control, the output voltage waveform can be adjusted.

Low-power applications that need for a single-phase AC voltage source frequently employ single-phase voltage source inverters (VSIs). Lighting systems, uninterruptible power supply (UPS), renewable energy systems, and medical equipment all often employ single-phase VSI. To provide variable speed and torque control of the motor, give a steady and dependable AC power source, dimming and brightness control of lights, synchronise with the grid, and provide accurate control of the equipment, the output voltage waveform may be adjusted.

Advantages of single phase VSI:

1. **Simple Design:**Compared to three-phase VSI, single-phase VSI has a simpler design, which lowers manufacturing costs and facilitates production.
2. **Cost-effectiveness:** Single-phase VSI is less expensive overall since it uses fewer components than three-phase VSI.
3. **Lightweight and Compact:**Single-phase VSI is better for applications with limited space since it is lighter and smaller than three-phase VSI.
4. **Controllable:** Due to its straightforward design and smaller number of components, single-phase VSI is simpler to regulate than three-phase VSI.
5. **Single-phase:** VSI is the best option for applications that need accurate speed control since it can regulate the variable speed of AC motors.

Disadvantages of single phase VSI:

1. **Lower Power Output:**Single-phase VSI is not suited for high-power applications since it has a lower power output than three-phase VSI.
2. **Low Power Factor:**Single-phase VSI has a low power factor, which might be problematic for some applications like energy efficiency and power factor correction.
3. Significant harmonic distortion can be a concern in various applications, including motor drives and renewable energy systems. Single-phase VSI can result in significant harmonic distortion in the output voltage waveform.

4. Single-phase VSI has trouble managing unbalanced loads, which might be problematic in some applications.

Three phase VSI: An electronic power converter called a three-phase voltage source inverter (VSI) is used to transform DC electricity into three-phase AC power. Variable frequency drive (VFD) applications frequently employ the VSI to regulate the speed of AC induction motors. Here is a thorough description of how a three-phase VSI operates:

1. **DC Power Source:** A battery or a rectifier can provide the DC voltage source that a VSI needs as an input.
2. **DC Bus Capacitor:** A DC bus capacitor is linked to the DC voltage and serves as a buffer to reduce voltage ripple.
3. Following that, a three-phase bridge inverter made up of six power semiconductor switches is linked to the DC voltage. These switches are often metal oxide semiconductor field-effect transistors (MOSFETs) or insulated gate bipolar transistors (IGBTs).
4. **PWM (Pulse Width Modulation):** PWM (Pulse Width Modulation) methods are used to regulate the switches in the VSI. A triangle waveform is compared to a reference sinusoidal waveform to produce the PWM signal. The resultant PWM signal regulates the switches' on/off times, which in turn regulates the output AC waveform's amplitude and frequency.
5. **Output Filters:**The three-phase AC waveform produced by the VSI may contain high frequency harmonics as a result of the PWM operation. Output filters made up of inductors and capacitors are added to remove these harmonics.
6. **Load:** An AC induction motor serves as an example of a three-phase load that is linked to the VSI's output. By changing the output waveform's amplitude and frequency, the VSI can regulate the motor's speed.

A three-phase VSI is a versatile and effective approach to regulate the speed of AC induction motors overall. It may be applied to many different things, such as pumps, fans, conveyors, and compressors.

Voltage Control in three - Phase Inverters: The output voltage and frequency of a three-phase voltage source inverter (VSI) are adjusted by varying the on/off periods of the six power semiconductor switches. In three-phase VSIs, there are primarily two techniques for controlling voltage:

The most popular technique for controlling voltage in three-phase VSIs is pulse width modulation (PWM) control. In PWM control, a sequence of pulses with a set frequency are produced by varying the on/off periods of the switches. To change the output voltage's amplitude, each pulse's width is altered. The voltage may be changed across a large range by varying the pulse widths. By altering the pulse train's frequency, the output voltage's frequency may likewise be changed.

High-performance motor drives frequently employ voltage vector control, a more sophisticated technique for controlling voltage. In voltage vector control, the magnitude and phase angle of a spinning voltage vector are changed to alter the output voltage. The voltage vector is produced by modulating the switch on/off timings in a predetermined manner. The output voltage may be varied widely by varying the magnitude and phase angle of the voltage vector. Altering the rotational voltage vector's speed is another way to alter the output voltage's frequency.

Both ways of controlling voltage have benefits and drawbacks. Although PWM control is easier to use and more common, the output waveform may contain high-frequency harmonics. Voltage vector control can offer higher performance and reduced harmonic distortion, but it is more complicated and demands more computing resources. The individual needs of the application determine the voltage control mechanism to be used.

Pulse Width Modulation Control: The most popular technique for controlling voltage in three-phase voltage source inverters (VSIs) is pulse width modulation (PWM). In PWM control, a sequence of pulses with a constant frequency are produced by varying the on/off periods of the six power semiconductor switches. To change the output voltage's amplitude, each pulse's width is altered. The three-phase VSI's PWM control mechanism is as follows:

1. **Creation of Reference Waveform:** The creation of a reference waveform is the initial stage in PWM control. Typically, this takes the shape of a sinusoidal wave with constant frequency and amplitude. The ideal output frequency of the VSI is normally the frequency of the reference waveform.
2. **Carrier Waveform Generation:** The carrier waveform generation process comes next. This often takes the shape of a triangle waveform with a set frequency and amplitude greater than the frequency of the reference waveform. The carrier waveform is utilised to calculate the switch on/off timings.
3. **Reference and Carrier Waveform Comparison:** The reference waveform and the carrier waveform are then compared. The difference between the reference and carrier waveforms at any particular moment determines the width of the subsequent series of pulses that are produced. The pulse width increases if the reference waveform is larger than the carrier waveform. The pulse width is reduced if the reference waveform is smaller than the carrier waveform.
4. **Switch Control:** The six switches in the VSI are then turned on and off using the pulse width signal. The matching switch is activated when the pulse width is high. The switch is shut off when the pulse width is small.
5. **Filtering of the output:** A sequence of pulses with a fixed frequency and variable amplitude are produced by the VSI. Filters made of inductors and capacitors are used to smooth out the pulses and eliminate any high-frequency harmonics in order to produce a sinusoidal output waveform.

In general, using PWM control to adjust a three-phase VSI's output voltage and frequency is straightforward and efficient. The output voltage's amplitude can be changed by changing the pulse width, and the output frequency can be changed by changing the reference waveform's frequency. To regulate the speed of AC induction motors, PWM control is frequently utilised in VFD applications.

Applications of three phase VSI: applications in a variety of sectors, including as grid-connected systems, motor drives, and power electronics. Here are a few typical uses for three-phase VSIs:

1. **Variable Frequency Drives (VFDs):** In industrial applications, VFDs are used to regulate the speed of AC motors. To transform DC power from a rectifier into AC power with variable frequency and voltage, three-phase VSIs are frequently employed in VFDs. The output voltage and frequency of the VSI are managed using the PWM control approach, which in turn manages the motor's speed.
2. **Renewable Energy Systems:** In renewable energy systems, such as wind turbines and solar PV systems, three-phase VSIs are used to transform DC electricity generated by the renewable source into AC power that can be supplied into the grid.

The output voltage and frequency of the VSI are adjusted to correspond to those of the grid.

3. Uninterruptible Power Supply (UPS) systems employ three-phase VSIs to convert DC power from batteries to AC power for important loads. To provide a steady and uninterrupted power supply to the loads, the output voltage and frequency of the VSI are controlled using the PWM control approach.
4. Three-phase VSIs are employed in active power filters to reduce issues with power quality in AC power systems, such as harmonic distortion. A smooth sinusoidal current waveform is produced by the VSI's injection of a voltage with harmonic content that is opposite to and equal to that of the load current.
5. Grid-connected systems, such as distributed generation and micro grids, employ three-phase VSIs to regulate the power flow between renewable energy sources and the grid. In order to provide a steady and balanced power exchange between the grid and the sources, the VSI regulates the output voltage and frequency.

Overall, three-phase VSIs are widely used in a variety of sectors where they provide dependable and efficient power conversion between DC and AC systems.

Advantages of three phase VSI: In comparison to other inverter types, three-phase voltage source inverters (VSIs) provide a number of benefits. The following are a few of the key benefits of three-phase VSIs:

1. Three-phase VSIs have a high power capability, making them appropriate for usage in industrial and commercial settings where a lot of power is required.
2. Power conversion with high efficiency is possible with three-phase VSIs, which leads to fewer power losses and more energy efficiency.
3. Smooth Output Voltage: Three-phase VSIs provide a smooth waveform of output voltage, making them excellent for powering delicate loads like computers, electronics, and motor drives.
4. Low Harmonic Distortion: Three-phase VSIs provide low harmonic distortion in the output waveform, which is crucial for applications like power factor correction and active filters where harmonic distortion can lead to issues.
5. Simple to regulate: Pulse width modulation (PWM) methods make it simple to regulate three-phase VSIs. The output voltage and frequency may be precisely controlled with PWM control, which is crucial for applications like variable frequency drives (VFDs).
6. Outstanding dependability: Three-phase VSIs are renowned for their extended service lives and outstanding dependability. They are frequently utilised in crucial applications including medical equipment and emergency power systems.
7. Compact Size: Three-phase VSIs are often smaller and lighter than other inverter types with comparable power ratings, making them simpler to carry and install.

Overall, three-phase VSIs are a preferred option for a variety of applications, including motor drives, renewable energy systems, UPS systems, and grid-connected systems [9], [10].

Disadvantages of three phase VSI: While three-phase voltage source inverters (VSIs) provide a number of benefits over other power conversion circuit types, there are a few drawbacks to take into account as well:

1. **Higher Cost:** Due to the need for additional power semiconductor devices and the complexity of the control circuitry, three-phase VSIs may be more expensive than single-phase VSIs.

2. **Harmonic Distortion:** A three-phase VSI's output voltage waveform has harmonic content that might impair the functionality of other connected machinery. To reduce harmonic distortion and guarantee a clean output waveform, filters must be used.
3. **Electromagnetic Interference (EMI):** In a three-phase VSI, the high-frequency switching of the power semiconductor devices can produce EMI, which can interfere with nearby electronic devices.
4. **Sophisticated Control:** A three-phase VSI requires more sophisticated control circuitry than a single-phase VSI, which makes the system's design and implementation more difficult.
5. Three-phase VSIs may produce a lot of heat, especially while working at high power levels, hence cooling requirements are necessary. For the system to operate reliably, proper cooling and heat dissipation are needed.

Overall, even though three-phase VSIs have numerous benefits, using them effectively and reliably requires careful consideration of both their drawbacks and the application's needs.

CONCLUSION

The Voltage Source Inverter (VSI) is a crucial component in many applications, such as electric vehicles, motor drives, and alternative energy systems. The output voltage and current waveforms of the VSI, which converts DC voltage to AC voltage, are significantly influenced by both its structure and control technique. Different topologies, including single-phase, three-phase, and multilevel, can be used to implement the VSI. Voltage control and current control are the two categories into which the control techniques may be divided. The individual application and the needed output voltage and current waveform determine the topology and control mechanism to be used. In conclusion, the VSI is a flexible tool with several applications that is essential to the current power electronics sector.

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CHAPTER 11

A BRIEF DISCUSSION ON AC–AC CONVERTERS

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ABSTRACT:

A power electronic circuit called an AC-AC converter, commonly referred to as an AC power controller, is used to change the frequency, voltage, or phase configuration of AC power. Applications for AC-AC converters include power supply, renewable energy systems, and motor drives. Power electronic circuits AC-AC converters are employed to change the frequency, voltage, or phase of AC power. They are often employed in many different applications, such as power supply, renewable energy systems, and motor drives. This chapter gives a general overview of AC-AC converters, including their workings, topologies, and uses.

KEYWORDS:

AC-AC Converter, AC Power, Cycloconverter, Voltage Regulator, Voltage Controller.

INTRODUCTION

A power electronic circuit called an AC-AC converter, commonly referred to as an AC power controller, is used to change the frequency, voltage, or phase configuration of AC power. Applications for AC-AC converters include power supply, renewable energy systems, and motor drives. Based on how they function, AC-AC converters may be divided into three primary groups: cycloconverters, AC voltage controllers, and AC voltage regulators. In applications like motor drives and wind turbine power generating systems, cycloconverters are utilised for low-frequency AC power conversion, generally less than 50 Hz. They have the ability to change both the frequency and the phase arrangement of AC electricity. Cycloconverters employ a matrix of thyristors to switch the AC power, and the thyristors' switching patterns control the output voltage waveform.

Higher frequencies, generally up to 400 Hz, are utilised for AC power conversion with AC voltage controllers, also known as phase angle controllers. They are employed in processes including heating, lighting, and motor speed regulation. In order to manage the output voltage magnitude, AC voltage controllers adjust the thyristors' conduction angles in the power circuit. For accurate AC voltage regulation, static voltage regulators also referred to as AC voltage regulators—are employed. They are utilised in projects like voltage stabilisation, uninterruptible power supply (UPS), and power conditioning. No matter how the input voltage or load circumstances vary, AC voltage regulators employ an electronic voltage regulator to keep the output voltage constant [1], [2].

The ability to change the frequency, voltage, or phase configuration of AC power is made possible by AC-AC converters, which are crucial parts of many power electronic systems. The intended output parameters, power level, and efficiency must all be carefully taken into account while designing and implementing AC-AC converters. The development of more effective and dependable AC-AC converter topologies as a result of developments in power semiconductor technology and control methods has allowed for their usage in a variety of applications.

In its most basic form, a power electronic ac-ac converter absorbs electrical power from one system and transforms it so that it may be sent to another ac system with waveforms that differ in amplitude, frequency, and phase. Depending on their power levels, they may be single- or three-phase kinds. Ac voltage controllers, sometimes referred to as ac regulators, are ac-ac converters used to change the rms voltage across the load while maintaining a constant frequency. The voltage control is carried out using either (2) on/off control under forced commutation/self-commutation using fully controlled self-commutated switches, such as gate turn-off thyristors (GTOs), power transistors, integrated gate bipolar transistors (IGBTs), MOS-controlled thyristors (MCTs), integrated gate-commutated thyristors (IGCTs), etc. Cycloconverters are ac-ac power converters that directly convert ac power at one frequency to ac power at another frequency without the need for an intermediate dc conversion link (as with inverters).

When the maximum output frequency is constrained to a small portion of the input frequency, the majority of cycloconverters operate on naturally commutated SCRs. Recently developed matrix converters with bidirectional on/off control switches, forced commutated cycloconverters, or fast-acting fully controlled switches all offer independent control of the magnitude and frequency of the generated output voltage, as well as sinusoidal modulation of output voltage and current. While soft-starting, online transformer tap changing, lighting and heating control, as well as speed control for pump and fan drives, are common uses for ac voltage controllers, cycloconverters are primarily used for high-power, low-speed, large ac motor drives for use in ship propellers, cement kilns, and rolling mills. This chapter introduces the power circuits, control strategies, and functioning of the ac voltage controllers, cycloconverters, and matrix converters. Their applications also receive a cursory evaluation.

Types of AC-AC converters: AC-AC converters are employed to change the frequency, voltage, or phase of AC power. AC-AC converters are widely used in many applications, including motor drives, renewable energy systems, and power supplies. Cycloconverters, AC voltage controllers, and AC voltage regulators are the three primary categories of AC-AC converters.

Cycloconverters: Cycloconverters are AC-AC power converters that can change the frequency and phase configuration of AC electricity. In applications like motor drives and wind turbine power generating systems, cycloconverters are utilised for low-frequency AC power conversion, generally less than 50 Hz. Cycloconverters employ a matrix of thyristors to switch the AC power, and the thyristors' switching patterns control the output voltage waveform. Step-down and step-up cycloconverters are the two primary kinds. High-frequency AC power is converted to low-frequency AC power using step-down cycloconverters, while low-frequency AC power is converted to high-frequency AC power using step-up cycloconverters. Due to the large number of thyristors needed and the intricate control circuitry necessary to switch them, cycloconverters are often less efficient than other forms of AC-AC converters.

AC voltage controllers: Also referred to as phase angle controllers, AC voltage controllers are used to convert AC power at higher frequencies, generally up to 400 Hz. They are employed in processes including heating, lighting, and motor speed regulation. In order to manage the output voltage magnitude, AC voltage controllers adjust the thyristors' conduction angles in the power circuit. The average output voltage may be changed by changing the conduction angle, producing a variable AC voltage. There are two primary groups of AC voltage controllers: single-phase and three-phase. The voltage of single-phase AC power is controlled by single-phase AC voltage controllers, whereas the voltage of three-phase AC power is controlled by three-phase AC voltage controllers. Because the control circuitry is simpler and there are fewer thyristors needed, AC voltage controllers are often more effective than cycloconverters.

Static voltage regulators, commonly referred to as AC voltage regulators, are used to regulate AC voltage precisely. They are utilised in projects like voltage stabilisation, uninterruptible power supply (UPS), and power conditioning. No matter how the input voltage or load circumstances vary, AC voltage regulators employ an electronic voltage regulator to keep the output voltage constant. The use of electronic voltage regulation, which does away with the necessity for power semiconductor switches, makes AC voltage regulators the most effective form of AC-AC converter.

Single-phase and three-phase AC voltage regulators fall into two primary groups. The voltage of single-phase AC power is regulated by single-phase AC voltage regulators, whereas the voltage of three-phase AC power is regulated by three-phase AC voltage regulators. The use of electronic voltage regulation and the complexity of the control circuitry make AC voltage regulators the costliest form of AC-AC converter.

AC-AC converters are a crucial part of many power electronic systems because they allow for the conversion of AC power between different frequency, voltage, and phase configurations. The application requirements, including the intended output specs, power level, and efficiency, determine the best AC-AC converter to use. The development of more effective and dependable AC-AC converter topologies as a result of developments in power semiconductor technology and control methods has allowed for their usage in a variety of applications [3]–[5].

DISCUSSION

Cycloconverter: A power electronic circuit called a cycloconverter is used to change AC power from one frequency to another. A cycloconverter may generate a variable frequency output as opposed to a traditional AC-AC converter, which employs a constant frequency output. Cycloconverters are utilised in many different applications, such as frequency changers, wind power production systems, and motor drives.

Step-down and step-up cycloconverters are the two primary kinds. High-frequency AC power is converted by step-down cycloconverters into low-frequency AC power, while low-frequency AC is converted by step-up cycloconverters into high-frequency AC power. Below, both cycloconverter kinds are explored.

Step-down Cycloconverters: High-frequency AC electricity is transformed into low-frequency AC power using a step-down cycloconverter. It may be further divided into single-phase and three-phase systems. For converting single-phase AC power, three-phase step-down cycloconverters are used, while single-phase step-down cycloconverters are used for converting single-phase AC power.

Simplified Step-down Cycloconverters: A single-phase step-down cycloconverter switches the AC input power using two back-to-back thyristors. The output frequency is set by the variable delay angle at which the thyristors are activated. By adjusting the delay angle, the output frequency may be changed. The number of input cycles required to produce each output cycle determines the single-phase step-down cycloconverter's output voltage. A single-phase step-down cycloconverter, for instance, will require five input cycles to produce each output cycle if it is intended to produce 10 Hz output from a 50 Hz input. The average input voltage throughout the course of the five input cycles is used to calculate the output voltage.

Step-down in three phases Cycloconverters: Three-phase AC power is converted using a three-phase step-down cycloconverter. The power from the AC input is switched using a matrix of thyristors. The output frequency may be changed by adjusting the thyristors' delay angle. The number of input cycles utilised to produce each output cycle, as well as the phase shift between the input and output voltages, define the output voltage of a three-phase step-down cycloconverter. The average input voltage throughout the input cycles utilised to create each output cycle, as well as the phase difference between the input and output voltages, are used to calculate the output voltage [6]–[8].

Step-up Cycloconverters: To transform low-frequency AC power into high-frequency AC power, a step-up cycloconverter is utilised. Additionally, it may be divided into two groups: single-phase and three-phase. For converting single-phase AC power, three-phase step-up cycloconverters are used, while single-phase step-up cycloconverters are used for converting single-phase AC power.

Monophasic Step-up cycloconverters: a step-up for one phase a pair of back-to-back thyristors are used by the cycloconverter to switch the AC input power. The output frequency is set by the variable delay angle at which the thyristors are activated. By adjusting the delay angle, the output frequency may be changed. The quantity of output cycles produced from each input cycle determines the single-phase step-up cycloconverter's output voltage. A single-phase step-up cycloconverter, for instance, will produce five output cycles for every cycle of its input if it is intended to produce 50 Hz output from a 10 Hz input. The average input voltage over the course of the input cycle determines the output voltage.

Three phase step-up cycloconverters: Three-phase AC power is converted using a three-phase step-up cycloconverter. In three-phase systems, low-frequency AC power is transformed into high-frequency AC power using a device known as a three-phase step-up cycloconverter. The input power is switched using a matrix of thyristors in this device. The output frequency may be changed by adjusting the thyristors' delay angle.

A three-phase step-up cycloconverter functions in a manner similar to a single-phase step-up cycloconverter, with the exception that it is made to operate with three-phase AC power. The input voltage is rectified, filtered, and converted to DC voltage, which is utilised to activate the matrix's thyristors. The output frequency may be changed to the appropriate value by altering the delay angle.

The number of output cycles produced from each input cycle, along with the phase shift between the input and output voltages, together define the output voltage of a three-phase step-up cycloconverter. The average input voltage throughout the input cycles utilised to create each output cycle, as well as the phase difference between the input and output voltages, are used to calculate the output voltage. By adjusting the phase shift between the input and output voltages as well as the number of output cycles produced from each input cycle, the output voltage may be changed.

AC voltage controllers: By changing the thyristors' conduction angle, AC voltage controllers are power electronics devices that are used to regulate the amplitude of AC voltage. They have a variety of uses, including regulating warmth, lighting, and motor speed.

Single-phase AC voltage controllers and three-phase AC voltage controllers are the two primary categories of AC voltage controllers.

Controllers for single-phase AC voltage: The power to single-phase AC loads like heaters, lights, and small motors is managed by single-phase AC voltage controllers. In situations where the load is resistive or has a low inductance, they are frequently utilised. Half-wave and full-wave are the two categories of single-phase AC voltage controllers. The most straightforward sort of AC voltage controller is the half-wave AC voltage controller. It is made up of a single thyristor that is linked to the load and the AC source in series. A lower output voltage is the result of the thyristor conducting the current for a portion of the AC cycle when it is activated. The thyristor's firing angle may be changed to regulate the output voltage.

A full-wave AC voltage controller is made up of two thyristors that are linked in the opposite direction of each other to the load and the AC supply. A portion of the AC cycle is conducted when one thyristor is activated, and the remaining amount is conducted when the other thyristor is triggered. By altering the firing angles of both thyristors, the output voltage may be controlled.

Controllers for three-phase AC voltage: Large motors and heating elements are examples of three-phase AC loads that are powered by voltage controllers for three phases of AC. In situations where the load is inductive or has a large inductance, they are frequently employed. Six-pulse and twelve-pulse three-phase AC voltage controllers are the two varieties.

Controller for six AC voltage pulses: A controller for six AC voltage pulses is made up of six thyristors placed in a three-phase bridge. The output voltage is controlled by firing the thyristors in pairs. The firing angle of the thyristors may be changed to regulate the output voltage.

Twelve-pulse AC voltage controller: Two six-pulse AC voltage controllers are wired in series to form a twelve-pulse AC voltage controller. The main side of a transformer is linked to the first six-pulse AC voltage controller, and the secondary side is connected to the second six-pulse AC voltage controller. The firing angle of the thyristors may be changed to regulate the output voltage.

In order to manage the power to AC loads, AC voltage controllers are widely utilised in a variety of applications. The kind of load and the required output voltage must be considered when choosing an AC voltage controller.

Single-phase and three-phase AC voltage regulators: AC voltage regulators are employed to regulate the voltage of AC electricity. They are employed in several processes, including voltage control, power conditioning, and voltage stabilisation. Single-phase and three-phase voltage regulators are the two primary varieties of AC voltage regulators.

Regulators for single-phase AC voltage: The voltage level of single-phase AC electricity is regulated by single-phase AC voltage regulators. When the load is relatively light, they are frequently employed in residential and commercial applications. Single-phase AC voltage regulators come in two varieties: tap-changing and electronic. A tap-changing voltage regulator is a particular kind of transformer that is used to control the AC power's voltage level. It is composed of a transformer with several taps on the main side, each of which may be moved to alter the voltage level. In applications where the load is rather steady, the tap-changing voltage regulator is frequently utilised.

Electronic Voltage Regulator:A solid-state device used to control the AC power's voltage level is known as an electronic voltage regulator. The voltage level is controlled by electronic components like thyristors and transistors. Applications with varying loads frequently employ the electronic voltage regulator.

AC voltage regulators for three phases: The voltage level of three-phase AC electricity is controlled by three-phase AC voltage regulators. They are frequently employed in industrial and commercial settings where the load is substantial and fluctuating. Three-phase AC voltage regulators come in two varieties: tap-changing and electronic. The main side of a three-phase transformer has numerous taps, but a tap-changing voltage regulator for three-phase AC power is comparable to the one used for single-phase AC power. By adjusting the tap positions on each phase of the transformer, the voltage level may be changed. In applications where the load is rather steady, the tap-changing voltage regulator is frequently utilised.

Electronic Voltage Regulator:A three-phase AC voltage regulator is similar to a single-phase AC voltage regulator, but it controls the voltage level using three-phase electronic components such thyristors and transistors. Applications with varying loads frequently employ the electronic voltage regulator.

In order to manage the voltage level of AC electricity, AC voltage regulators are crucial components. The kind of load and the required output voltage must be considered while choosing an AC voltage regulator. In contrast to the electronic voltage regulator, which is often used in applications where the load is changeable, tap-changing voltage regulators are typically utilised in situations where the load is rather steady.

Static voltage regulators: Electronic devices used to control and stabilise the output voltage of an AC power source are known as static voltage regulators, often referred to as solid-state voltage regulators. They are frequently utilised in situations where voltage fluctuations could hurt or interfere with delicate electronic equipment. Static voltage regulators work by modifying the input power source's voltage waveform. A DC voltage is produced by rectifying and filtering the input power source's voltage waveform. Electronic circuits then transform this DC voltage into an AC voltage waveform with a set amplitude and frequency. The load is then powered by this waveform of controlled AC voltage.

Static voltage regulators may be divided into two categories: step-down regulators and step-up regulators. When the input voltage is more than the needed output voltage, step-down voltage regulators are utilised. They work by lowering the input power source's voltage level to meet the load's needed output voltage. Depending on the AC power supply, single-phase or three-phase step-down voltage regulators are available.

Step-up voltage regulators: When the input voltage is less than the necessary output voltage, step-up voltage regulators are utilised. They work by raising the input power source's voltage level to the appropriate output voltage for the load. Depending on the AC power supply, single-phase or three-phase step-up voltage regulators are available.

Compared to other types of voltage regulators, such as tap-changing transformers or electromechanical voltage regulators, static voltage regulators provide a number of benefits. Several of these benefits include:

1. **Rapid response:** Static voltage regulators are perfect for sensitive electronic equipment that needs a constant voltage supply since they can react to voltage variations within microseconds.

2. **High efficiency:** The use of electronic components, which results in minimum power losses, makes static voltage regulators extremely efficient.
3. Static voltage regulators often weigh less and are smaller than other voltage regulators, which makes them simpler to install and maintain.
4. **Low maintenance:** Because static voltage regulators don't have any moving parts, they are less prone to damage and require little upkeep.

Static voltage regulators, however, can have a few drawbacks, such as:

1. **Costlier:** Because static voltage regulators use more sophisticated electrical components and technology than other voltage regulator types, they might cost more money.
2. Static voltage regulators are inappropriate for applications that call for high power outputs due to their restricted power capacity.

The output voltage of an AC power supply is controlled and stabilised by static voltage regulators, which are electrical devices. They differ from other types of voltage regulators in a number of ways, including quick reaction time, high efficiency, compact design, and low maintenance requirements. They do, however, have significant drawbacks, such as greater price and a lower power capacity. The particular needs of the application determine the type of voltage regulator that should be used.

Applications of AC-AC converters: AC-AC converters or AC power controllers change the voltage and frequency of an AC power supply to regulate the amount of power sent to a load. Due to its capacity to regulate the power given to a load and offer energy efficiency, AC-AC converters are used in a variety of sectors.

Following are a few uses for AC-AC converters:

1. **Motor speed control:** In commercial and industrial applications, AC-AC converters are used to regulate the speed of AC motors. The speed of the motor may be efficiently managed by adjusting the voltage and frequency given to it, which leads to energy savings and enhanced performance.
2. **Lighting control:** The brightness of lighting systems may be managed using AC-AC converters. The brightness of the lighting system may be adjusted to meet various lighting needs by changing the voltage and frequency of the AC power supply.
3. Controlling the electricity given to heating systems, such as ovens, furnaces, and heaters, is done using AC-AC converters. The temperature of the heating system may be efficiently adjusted by altering the voltage and frequency of the AC power supply, leading to energy savings and increased performance.
4. **Power conditioning:** The AC power given to delicate electronic equipment, such as computers, medical equipment, and telecommunications systems, is condition with the help of AC-AC converters. A steady and dependable power supply is provided to the load by the AC-AC converter by controlling the voltage and frequency of the AC power source, assuring optimal operation and safeguarding against voltage surges and dips.
5. **Renewable energy systems:** In order to convert the DC power generated by the system into AC power appropriate for use by the grid or the load, AC-AC converters are employed in renewable energy systems like wind turbines and solar photovoltaic systems. The AC-AC converter controls the voltage and frequency of the AC power sent to the grid, ensuring effective power distribution and the best possible performance of the renewable energy system.

6. AC-AC converters are used to regulate the power supplied to welding equipment. The AC-AC converter delivers the best possible power to the welding equipment by adjusting the voltage and frequency of the AC power supply. This improves welding performance while using less energy.

Due to their capacity to regulate the power given to a load and offer energy efficiency, AC-AC converters find a wide range of applications in many sectors. Motor speed control, lighting, heating, power conditioning, renewable energy systems, and welding equipment are a few of the frequent uses for AC-AC converters. The particular requirements of the application and the load determine the type of AC-AC converter to be used.

Advantages of AC-AC Converters: Because they have the capacity to regulate the amount of power sent to a load, AC-AC converters, sometimes referred to as AC power controllers, provide a number of advantages in a variety of applications. The following are a few benefits of AC-AC converters:

1. **Energy efficiency:** By controlling the voltage and frequency of the AC power sent to a load, AC-AC converters offer energy efficiency. The AC-AC converter lowers energy consumption and raises the system's overall efficiency by managing the power sent to the load.
2. **Performance enhancement:** AC-AC converters enhance the performance of several systems, including lighting, heating, and motors. The AC-AC converter enables appropriate power distribution to the load, improving performance and lowering energy consumption by adjusting the voltage and frequency of the AC power supply.
3. **Load flexibility:** AC-AC converters offer load flexibility by enabling real-time control of the power delivered to a load. They are therefore perfect for applications like heating and lighting systems where the power demands of the load change over time.
4. **Reduced maintenance expenses:** By shielding the load from voltage spikes and dips, AC-AC converters save maintenance costs. The AC-AC converter controls the voltage and frequency of the AC power sent to the load, protecting it from voltage fluctuations that might harm the load and need expensive repairs.
5. **Reduced noise:** By regulating the power given to a load in a smooth and continuous manner, AC-AC converters lower noise. This lessens the possibility of power spikes and dips, which can shorten the load's lifespan and generate noise in the load.
6. **Safety is improved:** AC-AC converters improve safety by shielding the load from voltage spikes and dips. The AC-AC converter guarantees that the load is protected from overvoltage and under voltage, which can harm the load and constitute a safety concern, by controlling the voltage and frequency of the AC power given to the load.

In a variety of applications, AC-AC converters have a number of benefits, including greater performance, flexibility with load, lower maintenance costs, quieter operation, and increased safety. The particular requirements of the application and the load determine the type of AC-AC converter to be used.

Disadvantages of AC-AC Converters:

1. **Cost:** When compared to conventional voltage regulators, AC-AC converters might be more costly. The price is affected by the kind of AC-AC converter and the particular needs of the application.
2. **Sophisticated control system:** To manage the voltage and frequency of the AC power supply, AC-AC converters need a sophisticated control system. Sensors, signal

processors, and control algorithms are all components of the control system, and their design and upkeep can be difficult.

3. **Harmonic distortion:** The AC power supply may experience harmonic distortion as a result of AC-AC converters. This may result in problems like lower power factor and electromagnetic interference (EMI), which may impair the functionality of other devices plugged into the same power source.
4. **Efficiency losses:** Because power electronics are involved in the conversion process, AC-AC converters may experience efficiency losses. These losses may result in higher total energy use and decreased system efficiency.
5. **Dissipation of heat:** The power electronics employed in AC-AC conversion cause the converters to produce heat. To keep the converter and the load from being harmed, this heat needs to be expelled.
6. **Limited Power Range:**Because of their limited power range, AC-AC converters might not be appropriate for applications that call for high power levels.

In addition to its many benefits, AC-AC converters also have certain drawbacks, such as high cost, a complicated control system, harmonic distortion, efficiency losses, heat dissipation, and a narrow power range. Prior to selecting an AC-AC converter for a particular application, these drawbacks should be carefully taken into account [9]–[11].

CONCLUSION

In order to change the frequency, voltage, or phase configuration of AC power, AC-AC converters are crucial parts of many power electronic systems. The intended output parameters, power level, and efficiency must all be carefully taken into account while designing and implementing AC-AC converters. The development of more efficient and dependable AC-AC converter topologies as a result of improvements in power semiconductor technology and control methods has allowed for their usage in a variety of applications, such as motor drives, renewable energy systems, and power supply. Even more improved AC-AC converter technologies are anticipated to result from additional research and development in this field, opening up new and creative power electronic applications.

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CHAPTER 12

POWER FACTOR CORRECTION CIRCUIT

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ABSTRACT:

Power factor is a metric for assessing how effectively a system uses electrical power and represents the proportion of real to perceived power. By lowering the phase gap between voltage and current, power factor correction (PFC) circuits are used to increase the power factor of electrical systems. As a result, power losses are decreased and energy efficiency is increased. This essay's goal is to give a general introduction of PFC circuits, including how they work and their benefits and uses.

KEYWORDS:

Active PFC Circuit, Passive PFC Circuit, Power Factor, Power Supply, Power Factor Correction, PFC, Reactive Power.

INTRODUCTION

Power factor is a word used to indicate how well a system uses electrical power. Voltage and current interact in electrical circuits to transmit power from the source to the load. However, the load does not use all of the power that the source provides. It loses some of it as heat or other types of energy, which lowers efficiency all around. A circuit's power factor is determined by comparing the real power, or the power actually consumed by the load, to the apparent power, or the sum of the circuit's voltage and current. To put it another way, power factor is a gauge of how well the current is put to use. The voltage and current both reach their greatest and minimum levels simultaneously in an ideal circuit because they are in phase. In this instance, the power factor is 1, meaning that the load is using all of the power from the source. However, the voltage and current are frequently out of phase in real-world circuits, which causes a power factor of less than 1.

Reactive components in the circuit, including inductors and capacitors, are what produce the phase mismatch between the voltage and current. Because of the cyclical energy storage and release in these materials, the voltage can lag or outpace the current. These components' energy storage and energy release are not used to do productive work; instead, they waste energy and reduce efficiency. Techniques for power factor correction can be used to raise a circuit's power factor. Adding a power factor adjustment capacitor in parallel with the load is one such technique. This capacitor efficiently balances out the reactive power in the circuit and moves the current closer to being in phase with the voltage by storing energy when the voltage is high and releasing it when the voltage is low. As a result, efficiency and power factor both rise. In industrial and commercial environments, where significant amounts of electrical energy are consumed, power factor adjustment is particularly crucial. In addition to increasing energy use, a poor power factor can put additional strain on the electrical system and result in equipment failure. Additionally, utilities may impose fines for poor power factor, which might lead to an increase in electricity costs [1], [2].

In other words power factor is a gauge of how effectively a system uses electricity. A low power factor means the circuit is not making the most use of the energy being provided, which reduces efficiency and increases energy consumption. Efficiency can be increased by using power factor adjustment techniques, such as putting capacitors in parallel with the load. In industrial and commercial environments, where significant quantities of electrical energy are consumed and low power factor can lead to equipment failure and higher costs, it is particularly crucial to improve power factor.

Power factor (PF) = Real power (Average) / Apparent power

$$PF = I_{rms}.V_{rms}.\cos\theta / I_{rms}.V_{rms} = \cos\theta$$

Power Factor Correction Circuit: An electrical system's power factor can be raised by using a power factor correction (PFC) circuit. The ratio of the real power to the apparent power is known as the power factor of a circuit, which measures how efficiently electrical power is being used. A low power factor means the circuit is not making the most use of the energy being provided, which reduces efficiency and increases energy consumption. A PFC circuit is made to address this problem by lowering the phase difference between the circuit's voltage and current, which raises the power factor.

PFC circuits are frequently utilised in situations like industrial and commercial ones that require a lot of power. In addition to increasing energy use, a poor power factor can put additional strain on the electrical system and result in equipment failure. Additionally, utilities may impose fines for poor power factor, which might lead to an increase in electricity costs. PFC circuits come in two flavours: passive and active. Passive PFC circuits adjust the power factor by using passive components like inductors and capacitors. Although they are less complicated and more affordable than active PFC circuits, they are less efficient. On the other hand, active PFC circuits utilise active elements like transistors and diodes to rectify the power factor. Although they are more costly and sophisticated, they provide superior efficiency and correction.

A capacitor is generally connected in parallel with the load in passive PFC circuits. The capacitor is selected to have a capacitance value that is high enough to account for the reactive power in the circuit and bring the current and voltage closer to being in phase. The capacitor successfully balances out the reactive power in the circuit by charging when the voltage is high and discharging when the voltage is low. Boost converters are frequently used in active PFC circuits since they are more complicated to fix the power factor. A particular kind of DC-DC converter called a boost converter is employed to raise the input signal's voltage. A feedback loop that monitors the input voltage and current and modifies the output voltage and current to correct the power factor controls the boost converter.

The feedback loop commonly includes a control circuit that modifies the output voltage and current using the pulse width modulation (PWM) approach. The AC input voltage is rectified to DC by a diode bridge in the active PFC circuit before being filtered by a capacitor. The boost converter is then fed the resultant DC voltage. A switch, an inductor, a diode, and a capacitor make up the boost converter. The control circuit's PWM signal, which controls the switch, is produced. The inductor stores energy from the input voltage when the switch is closed. The stored energy is transmitted to the output capacitor and load when the switch is opened. While the capacitor filters the output voltage, the diode stops the current from returning to the inductor.

An electrical system's power factor can be raised by using a power factor correction circuit. A low power factor means the circuit is not making the most use of the energy being provided, which reduces efficiency and increases energy consumption. While active PFC circuits employ active components like transistors and diodes to rectify the power factor, passive PFC circuits use passive components like capacitors to do so. Active PFC circuits are more costly and complicated, but they offer superior efficiency and correction. PFC circuits are crucial for enhancing electrical system efficiency, particularly in commercial and industrial environments where substantial quantities of electricity are utilised.

DISCUSSION

Need of PFC circuit: In the face of a planned use of natural resources, our society is now acutely conscious of the need to maintain the natural environment of our living things. The utility power source that we currently use was pure when it was created in the nineteenth century, much like the planet is today. Electrical power systems have benefitted humanity in every way for more than a century. Meanwhile, the condition of the power supply deteriorates as a result of the heavy usage of this utility. But it wasn't until the middle of the 1980s that the "dirty" atmosphere in the power system began to garner public attention [3], [4].

Since the start of the 20th century, ac power systems have been quickly adopted by businesses and households because they are the easiest kind of energy to create, transfer, and distribute. As the use of electrical energy has increased, the number of heavy loads linked to the power grid has increased as well. Large electricity users like the electrochemical and electrometallurgical industries installed capacitors as VAR compensators in their systems throughout the 1960s to reduce the amount of money they needed to pay to the utility companies and to stabilise the supply voltages. Harmonic currents are taken from the line as a result of the low impedance that these capacitors exhibit in the system. There will be and spread line voltage distortion as a result of the non-zero system impedance. The system performance can be negatively impacted by the contaminative harmonics in a number of ways, including:

(a) The equipment capacity is not used effectively (low power factor) as a result of the line rms current harmonics, which do not supply any real power in Watts to the load.
(b) Harmonics will lower transmission efficiency and result in heat issues in transformers by increasing conductor loss and iron loss.
(c) A three-phase system is severely harmed by the odd harmonics, which overload the unprotected neutral conductor.
(d) In order to protect the stability of system operation, oscillation in the power system must be completely avoided.
(e) Automatic relay protection devices may malfunction under conditions of high peak harmonic currents.
(f) Harmonics may result in additional issues such as audible noise, insulation failure, product defect rates, electromagnetic interference that prevents communication, deterioration of electrical equipment dependability, etc.

When static VAR compensators (SVCs) were widely utilised for electric arc furnaces, metal rolling mills, and other high power appliances in the early 1970s, harmonic pollution may have had its biggest effect. Odd order harmonic currents, which are particularly detrimental to three-phase power systems, are created by incomplete conduction of SVC. The operations of other devices linked to the same system as well as, in some cases, the operations of the devices themselves that produce the harmonics can be impacted by harmonics.

The first technical standard IEEE519-1981 with regard to harmonic control at point of common coupling (PCC) was released in the early 1980s, but it was not until then that the continuously deteriorating supply environment became a significant issue. This standard's release was significant because it not only gave design engineers and manufacturers a technical reference, but it also paved the way for future research in the fields of harmonic reduction and power factor correction (PFC). Researchers and industrial users were encouraged by the harmonic control legislation to create low-cost devices and power electronic systems to minimise harmonics because it is neither practical nor required to do so.

In the early 1990s, research on PFC and harmonic reduction accelerated. Power electronic systems have grown and expanded to new and diverse application ranges from residential, commercial, and aerospace to military and others due to the rapid growth in power semiconductor devices. More and more interfaces are being switched into power systems as a consequence of the evident superiority of power electronic interfaces like switch mode power supplies (SMPS) over conventional linear power supplies. Even though SMPSs have a high level of efficiency, their non-linear behaviour causes them to draw distorted current from the line, which leads to high total harmonic distortion (THD) and poor power factor (PF).

Practical SMPSs employ a large electrolytic capacitor in the output side of the single-phase rectifier to reduce output voltage ripple. The power supply draws a high rms pulsing line current because the rectifier diodes only work when the line voltage is higher than the capacitor voltage. As a result, these power systems have significant THD and low PF (often less than 0.67). Although no one item poses a particularly substantial harmonic current hazard, the widespread adoption of such systems might worsen the state of the utility power supply. Government regulatory authorities continue to recognise that diminishing power quality is a problem that has to be addressed in recent years. Many different circuit topologies and control techniques have been developed as a result of the increasing attention on harmonic reduction and PFC due to the introduction of mandatory and stricter technical standards like IEC1000.

In general, passive technique and active approach are two categories of solutions for harmonic reduction and PFC. great dependability, great power handling capacity, and ease of construction and maintenance are benefits of the passive method. However, the functioning of a passive compensation system does not provide a high PF and is very reliant on the power system. The active technique rules the low to medium power applications because to its exceptional performance (PF and efficiency close to 100%), regulatory abilities, and high density, even if the passive approach can still be the best option in many high power applications. The majority of passive power processing devices are often replaced by active power electronic systems when the power handling capacity of power semiconductor devices is increased to megawatts [5], [6].

Harmonic reduction and PFC methods for reducing distortion are currently being developed. PFC methods are increasingly being adopted by the power supply companies for all off-line power sources. A review of several active harmonic reduction and PFC strategies found in the free literature is provided in this chapter. The main goal of authoring this chapter was to provide a quick overview of these strategies and references for upcoming scholars in this field. The definitions of THD and PF, typical control methods, and numerous converter topologies are all covered in this topic. Finally, the Summary Section emphasises the potential future research trends.

Passive Power Factor Corrector: Passive power factor correctors are typically employed in high power line applications due to their excellent dependability and high power handling capacity. For heavy plant loads, such as arc furnaces, metal rolling mills, electrical locomotives, etc., series tuned LC harmonic filters are frequently utilised. A connection schematic for a harmonic filter and a line frequency switching reactor static VAR compensator is shown in Figure 1. The filter shunts the harmonic currents by tuning the filter branches to odd harmonic frequencies. The filter additionally offers capacitive VAR for the system since each branch exhibits capacitive at line frequency. In order to maintain a higher PF, the thyristor-controlled reactor maintains an optimised VAR compensation for the system.

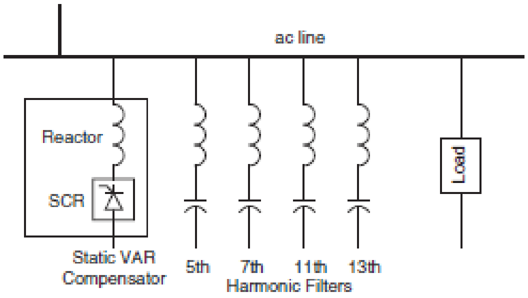

Figure 1: Series tuned LC harmonic filter PF corrector.

Due to the unpredictability of the system impedance and harmonic sources, the design of the tuned filter PF corrector is particularly challenging. Additionally, this approach uses a lot of pricey components and takes up a lot of room.

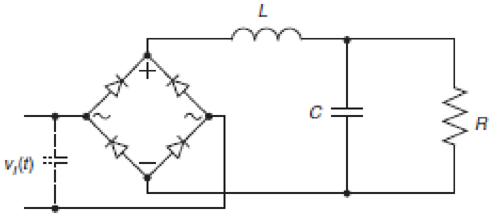

Figure 2: Inductive-input PF corrector.

The tuned filter PF corrector might not be the best option for cases where the power output is less than 10kW. The inductive-input filter, seen in Figure 2, is the most typical off-line passive PF corrector. A maximum PF of 90% may be produced by this circuit, depending on the filter inductance.

Power factor improvement methods: Three basic strategies may be used to raise power factor such as Synchronous condensers, capacitor banks, and phase advancers.

Capacitor banks: Reduced voltage and current phase differences are a sign of improved power factor. Reactive power is necessary for the bulk of loads to operate since they are inductive in nature. This reactive power is provided by a capacitor or bank of capacitors arranged in parallel with the load. They serve as a local source of reactive power, which reduces the amount of reactive power flowing over the line. The phase gap between the voltage and the current is lessened using capacitor banks.

Synchronous condensers: Synchronous condensers are three phase synchronous motors without an associated load. Depending on the excitation, the synchronous motor has the ability to operate under any power factor, including leading, lagging, or unity. A synchronous condenser linked to the load side and overexcited is used for inductive loads. It operates like a capacitor thanks to synchronous condensers. It either provides the reactive power or pulls the lagging current from the supply.

Phase advancers: This AC exciter is mostly used to raise an induction motor's PF. They are attached to the motor's rotor circuit and installed on the motor shaft. By offering the stimulating ampere turns necessary to generate the necessary flux at the specified slip frequency, it raises the power factor. It may also be made to function at the leading power factor by increasing the ampere-turns.

Types of PFC circuit: Electronic devices employ PFC circuits, also known as power factor correction circuits, to increase the power factor of the input current waveform. A low power factor can result in a number of problems, including higher energy consumption and worse power quality. The power factor is a measurement of how well a device utilises the incoming power. By modifying the input current waveform to make it more sinusoidal and in-phase with the voltage waveform, PFC circuits seek to increase the power factor. PFC circuits come in a variety of forms, each with unique benefits and drawbacks. We'll talk about some of the most typical PFC circuit types in this response.

1. **Passive PFC circuits:** Passive PFC circuits modify the input current waveform using passive parts like capacitors and inductors. Although they are very cheap and simple, they don't do much to increase the power factor. Small electronic devices and other low-power applications frequently employ passive PFC circuits.
2. **Active PFC circuits:** Active PFC circuits modify the input current waveform using active elements like transistors and diodes. They are more costly and sophisticated than passive PFC circuits, but they also do a better job of boosting power factor. High-power applications, such as the power supply for computers and servers, frequently employ active PFC circuits.
3. **Boost PFC circuits:** A boost converter is used in a boost PFC circuit type to modify the waveform of the input current. A DC-DC converter called a "boost converter" raises input voltage, which raises input current and modifies waveform. Although boost PFC circuits are effective and efficient, careful design is necessary to prevent problems like voltage spikes and electromagnetic interference.
4. **Buck-boost PFC circuits:** A buck-boost converter is used in buck-boost PFC circuits to modify the waveform of the input current. Depending on the design, the buck-boost converter can change the input voltage, giving you more control over how the waveform is shaped. Although buck-boost PFC circuits can be more costly and complex than boost PFC circuits, they are also as efficient and effective.
5. **Flyback PFC circuits:** A flyback converter is used in flyback PFC circuits to modify the waveform of the input current. A transformer-based converter called a flyback converter has the ability to change the input voltage depending on the design. Flyback PFC circuits can have larger ripple currents and worse efficiency than other PFC circuits while being very simple and affordable.

There are various different types of PFC circuits available, each with unique benefits and drawbacks. PFC circuits are a crucial component in many electrical systems. The unique application criteria, such as power level, efficiency, and cost, determine which PFC circuit should be used.

Applications of PFC circuits: By boosting the power factor and lowering the harmonic distortion of the input current, the Power Factor Correction (PFC) circuit increases the efficiency of AC power sources. PFC circuit applications include some of the following:

1. **LED lighting:** To boost power supply efficiency, decrease harmonic distortion, and lengthen the lifetime of the LEDs, PFC circuits are frequently employed in LED lighting applications.
2. **Computer Power Supplies:**To increase efficiency and lower the system's power usage, PFC circuits are frequently utilised in computer power supply.
3. **Industrial Power Systems:**To decrease harmonic distortion of the input current and enhance power factor, PFC circuits are employed in these systems. This lowers energy usage and increases system dependability.
4. **Electric Vehicle Charging:**To increase power supply effectiveness and lower harmonic distortion of the input current, PFC circuits are utilised in electric car charging stations.
5. PFC circuits are used in solar inverters to decrease harmonic distortion of the input current and increase power conversion efficiency.
6. **HVAC Systems:**To increase power factor and lower energy consumption, PFC circuits are used in HVAC systems (heating, ventilation, and air conditioning).

PFC circuits are generally employed in power electronics applications that need high reliability, low harmonic distortion, and high efficiency.

Advantages of PFC circuit: In power electronics applications, the Power Factor Correction (PFC) circuit has a number of benefits, including:

a) **Increased efficiency:** By lowering power losses and raising the power factor, PFC circuits may greatly increase the efficiency of power supply. As a result, there will be less heat generated, less energy used, and longer equipment lifespan.
b) **Respect for power restrictions:** The power factor of electrical equipment is subject to laws in several nations. Equipment may adhere to these rules and avoid fines or penalties thanks to PFC circuits.
c) A cleaner and more reliable power supply is the outcome of PFC circuits' ability to reduce harmonic distortion in the input current. This leads to an improvement in power quality.
d) **Prolonged Equipment Lifespan:**PFC circuits, which offer a more reliable and efficient power supply, can lessen the strain on electrical equipment. This can increase device longevity and lower maintenance expenses.
e) **Reduced Operating Costs:**PFC circuits' greater efficiency can result in considerable energy bill reductions, especially in high-power applications where energy expenses are a major expenditure.
f) **Improved Environmental Impact:**PFC circuits can help equipment have a smaller carbon footprint by using less energy and operating more efficiently.

PFC circuits are advantageous for power electronics designers that want to maximise the effectiveness, dependability, and environmental impact of their products.

Disadvantage of PFC circuit: While Power Factor Correction (PFC) circuits have a number of benefits, there are a few drawbacks to take into account, including:

a) **Added complexity:** PFC circuits need for extra parts like control circuits and boost converters, which can make the system more complicated.
b) **Costlier:** The PFC circuits' additional components can make the system more expensive, especially for low-power applications where price is a major factor.
c) PFC circuits may not be as efficient at low loads, which can lead to an increase in energy usage in situations where the load fluctuates greatly.

d) **Increased stress on components:** PFC circuits may subject capacitors to greater stress, which might shorten their lifespan and drive up maintenance costs.
e) The high-frequency switching necessary for PFC circuits has the potential to cause electromagnetic interference (EMI), which might affect the functioning of nearby equipment.
f) **Problems with compatibility:** PFC circuits could not work with all types of loads, especially those with nonlinear characteristics, which could restrict their usage in some situations.

To assess if the advantages outweigh the costs and potential problems, it is important to thoroughly examine the pros and cons of PFC circuits within the context of the particular application [7], [8].

CONCLUSION

Circuits for power factor adjustment are necessary to increase the energy efficiency of electrical systems. PFC circuits decrease power losses and raise the system's overall power factor by lowering the phase mismatch between voltage and current. As a result, there is a decrease in energy use and power costs. Electric cars, renewable energy systems, and power electronics are just a few of the areas where PFC circuits are used. They are a crucial instrument for attaining energy efficiency and cutting carbon emissions.

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CHAPTER 13

A BRIEF DISCUSSION ON GATE DRIVE CIRCUITRY

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ABSTRACT:

A voltage signal is provided by gate drive circuitry to switch on and off power semiconductor devices. In order to provide the best possible power electronics solutions, this chapter provides an overview of the important factors, typical topologies, and developing developments in gate drive technology. In order to switch on and off power semiconductor devices like MOSFETs and IGBTs, gate drive circuitry is a critical part of power electronics systems. The design and operation of gate drive circuits are reviewed in this article, with an emphasis on important factors and concerns such voltage and current ratings, switching speed, and safety features. The common topologies and components utilised in gate drive circuits are also covered in this chapter, along with new developments in gate drive technology.

KEYWORDS:

Gate Drive Circuitry, Gate Drivers, Level Shifting, Power Electronic System, Power Semiconductor Devices.

INTRODUCTION

To switch on and off power semiconductor devices like MOSFETs and IGBTs, gate drive circuitry is a crucial part of power electronics systems. Many high-power applications, such as motor drives, power supply, and renewable energy systems, depend on these devices as essential components. The purpose of gate drive circuitry is to transmit a voltage signal to the semiconductor device's gate terminal, which turns the device on and off. To guarantee optimum device performance and dependability, the gate drive signal must adhere to a set of requirements, including voltage and current levels, switching speed, and protective features. Gate drive circuits design and implementation must also take into account the needs of the particular application, such as operating voltage and current levels, temperature range, and system complexity. The achievement of high system efficiency, the reduction of switching losses, and the avoidance of device failure depend on the proper gate drive circuitry design [1]–[3].

In addition to fundamental parameters and considerations, typical topologies and components, and new developments in gate drive technology, this article presents an overview of gate drive circuits. Gate drive circuitry's underlying concepts may be understood by designers, who can then create solutions that are optimised for the particular power electronics applications they are working on. A gate driver circuit is a kind of electrical circuit used in high-power applications to regulate the switching of power transistors like MOSFETs or IGBTs. In switching power supply, motor drives, and other power electronic systems, these circuits are crucial. The power transistor's gate must be driven appropriately for the transistor to switch on and off rapidly and effectively. This is ensured by the gate driver circuit. This is significant in high-frequency applications when the system's overall performance depends on the transistor's switching rate. Although there are several kinds of gate driver circuits, they all typically include an output stage, a power supply, and a control circuit. The gate driver receives the input signal from the control circuit and amplifies it before feeding it to the power transistor with the requisite voltage and current. The output stage transmits the amplified signal to the power transistor's gate, and the power supply supplies the gate driver circuit with the appropriate voltage and current. Depending on the demands of the application, gate driver circuits may be developed using discrete components or integrated circuits and range in complexity. To guarantee the safe and dependable functioning of the power electronic system, certain gate driver circuits additionally include functions like overcurrent protection, overvoltage protection, and temperature monitoring.

Over the last three decades, there has been a global trend towards energy efficiency, which has prompted a demand for technical breakthroughs in the design and management of power electronic converters for energy processing. These power electronic converters are used in a variety of industries, including:

1. Electronic devices
a) Power supply for computers and mobile phone and camera batteries
b) Automobile industries: Electronic lighting and ignition
2. Commercial industries: Industrial welding, Induction heating systems for treating metals, Uninterruptible Power Supplies (UPS), and Variable Speed Motor Drives for Conveyor Belt Systems.
3. Electronics used in the home, such as washing machines, dishwashers, and lighting that is fluorescent, compact fluorescent, or incandescent
4. DC transmission for electrification purposes in utility applications

Power converter topologies are used by all of the aforementioned applications. Using semiconductor technologies like BJT transistors, SCRs (thyristors), IGBTs, and power MOSFETs, this enables regulated and effective power conversion from one kind of energy to another. The adage "Power is nothing without control" from Pirelli Tyres is undoubtedly accurate. A power converter's gate drive circuitry serves as a crucial interface between the high power electronics and the phases of intelligent control processing. Because it may significantly affect the performance and dependability of a power electronic system, it is crucial that this interface between the control and power electronics be effectively built illustrates in Figure 1.

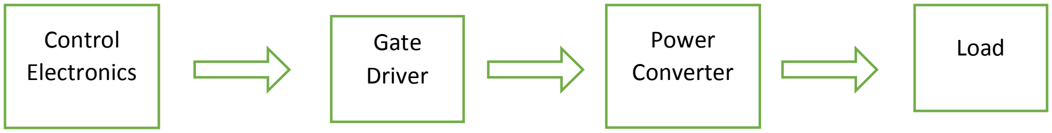

Figure1: Generalized layout of a power electronic system showing the situation of the gate driver circuits.

Semiconductor Drive Requirements: The cut-off mode, the active mode, and the saturation mode are the three operational states of power semiconductor devices. The goal is to operate these semiconductors in either the cut-off region or the saturation region in switch-mode power electronic converters in order to facilitate maximum power conversion efficiency while minimising the transition through the active or linear region. A good gate driver circuit is necessary to accomplish these quick transition times. In order to accomplish turn-on and turn-off, this gate driver must be able to give the required charge to the power semiconductor device gate junction. Regarding driving needs, power semiconductors may be divided into two groups: current-driven devices and voltage-driven devices.

DISCUSSION

Current-driven Devices:A device that needs a steady current drive for a while in order to begin and/or maintain conduction is said to be current-driven. The bipolar power transistor and the thyristor (SCRs) are two widely used categories of current-controlled electronics. SCRs are often employed in AC-DC converters like controlled rectifiers, where the input AC voltage aids in commutating (turning off) the devices by reversing polarity. In DC– AC inverters, the gate turn-off thyristors (GTOs) are generally used owing to their ability to be both switched on and off by a gate control signal. Due to the lack of an AC input voltage with reverse polarity in these applications, forced commutation circuitry was required to turn the thyristor off. The high voltage and high current applications, such as DC transmission, which call for converters in the megawatt range, are still dominated by thyristors and GTOs. The usage of thyristors and GTOs in traditional power converters has decreased as a consequence of the development of the IGBT power semiconductor device. IGBTs with on-state currents of several hundred amps and blocking voltages over 1.7 kV are easily accessible. IBGTs are substantially more efficient at switching than thyristors and consume far less power for the gate drive than either SCRs or power bipolar junction transistors (BJT). Due to their improved performance, power BJTs have already been superseded by IGBTs in the majority of applications. In the future, SCR and GTO devices could potentially be totally replaced by IGBT devices with blocking voltages above 4 kV, thanks to the next generation of silicon carbide technology [4].

Voltage-controlled Devices: These components are semiconductors, and in order to maintain conduction, they need a continuous voltage drive applied to the gate control terminal. These devices are the favoured option in contemporary power electronics because they have input drive requirements that are far lower than those of their current-driven equivalents. Power MOSFETs and IGBTs are two examples of forced commutated switching devices that, in typical operation, are completely controlled at the gate terminal. These devices don't latch into conduction, therefore specific commutation circuits are not needed. In contrast to transistors, a MOSFET and an IGBT's gate input junction is entirely capacitive, hence no gate drive current is required in the steady state. However, for the device gate to continue conducting, a minimum gate drive voltage must be maintained (above the gate threshold voltage). To quickly switch the device, a high current, low impedance drive circuit is required to inject or withdraw current from the gate at high slew rates. Even though it is modest, the gate drain capacitance may need a substantial amount of charge under certain conditions (the Miller effect).

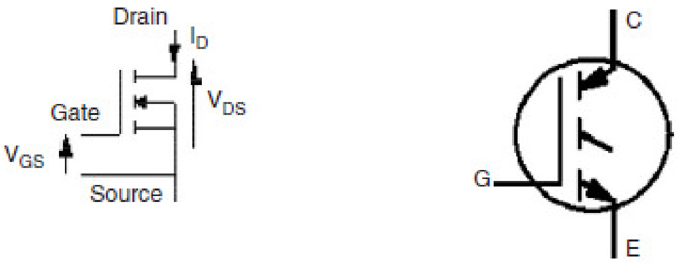

Figure 2: Static model representation of the power MOSFET and IGBT power semiconductor devices.

Research is still being done on how to provide the required power for the effective driving of voltage-controlled devices. However, the gate driver circuitry necessary to operate power MOSFETs and IGBTs in the bridge circuit design will be the exclusive emphasis of this chapter. The power MOSFET and IGBT are depicted here in their most basic symbolic representations. The static model of these devices is shown in Figure2. IGBTs may be produced without the integrated body diode, unlike power MOSFETs. The integral body diode, which is always included in a MOSFET device, is often left out of representations of power MOSFETs like the one below. When reading circuits, care should be taken to remember this additional, invisible component.

Gate Drivers for Power Converters: There are many different configurations of power electronic converters. Each features an intricate switching mechanism with the aim of converting energy effectively. This converter produces a variety of floating potentials are used to create an AC or output characteristics that are close to DC. Gate operators serve as signal converters and current buffers. They communicate the two needed switching state data and gate drive power during the switching of power semiconductors.

Floating Supply: A device's gate terminal has to be turned positive in relation to its source or emitter in order to push it into conduction, such as with an IGBT or power MOSFET. The idea that since the emitter or source terminal is often at some ground potential, it must be turned positive with regard to ground is one that many novices to the area of power electronics hold. It should be observed that the emitter terminal of IGBT1 in the circuit above is not referred to the system ground potential and instead may be floating anywhere between ground and the DC bus potential depending on the operational states of IGBT1 and IGBT2. Therefore, any circuitry connected to this floating midway potential needs a supply to be powered. The term "floating supply" is often used to describe this kind of supply. The next section describes three of the most popular techniques for creating a floating supply. The Simple structure of a bridge topology and driving circuit illustrating the concept of a high-side switch illustrated in Figure 3.

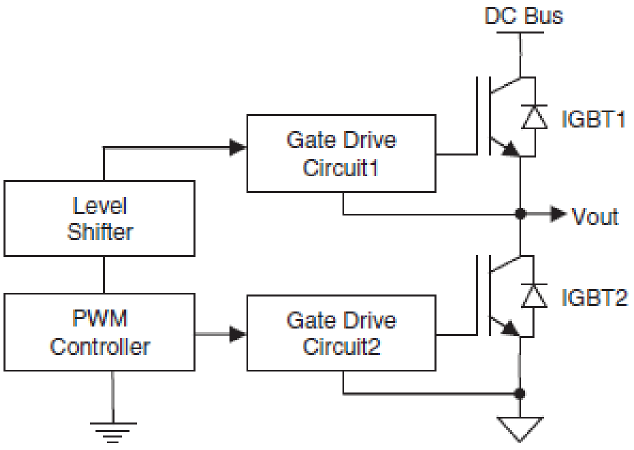

Figure 3: Simple structure of a bridge topology and driving circuit illustrating the concept of a high-side switch.

a. **Limited Access:** Utilising a transformer isolated supply is the easiest method of creating a floating supply. This kind of supply is able to provide a constant, high quantity of current when compared to other approaches. A mains frequency transformer supply is inexpensive yet often rather large. A significantly smaller isolation transformer may be used to provide an isolated floating supply when a high frequency isolated DC-DC converter is used and supplied from an existing DC supply.

b. **Charge-pump Provision:** The voltage of one source is added to another using the charge-pump method. In most cases, it is used to provide a boost voltage in addition to the primary high-voltage supply. For the purpose of producing a boost voltage to power floating high side circuitry, the charge-pump supply is not appropriate. The charge-pump method has the advantage of maintaining a constant supply to the circuit. This circuit is not often utilised for power converters due to its complexity and high cost.

c. **Bootstrap Provision:** The bootstrap supply is a widely used method for creating a floating supply and consists of a simple circuit with only one diode and a supply storage capacitor. This method is often used in converters up to several kilowatts for low-cost solutions. Variable speed motor drives and electronic ballasts are examples of common uses.

Level Shifting: The control signal provided from the PWM electronics must be sent to the floating driver circuitry, which is the second prerequisite for operating a high-side switch. To do this, a level-shifting circuit is necessary. The high- and low-side gate drive circuits are designated as GD1 and GD2, respectively. The control signal V1, which is referred to the ground potential of the control circuit, must be referenced to the floating potential Vout at the IGBT1 emitter in order to notify the high-side gate driver circuitry to begin turning on the high-side IGBT switch. As illustrated in Figure. 4, this suggests that the control signal V1 will be level shifted to Vg1. An isolating black box that transmits a signal over a potential barrier is what a level shifter is conceived. Vg1 will be able to reach a maximum level of Vout + V1. These values may exceed 500V in power converters that run on mains voltage. One of the following techniques is used to produce level shifting:

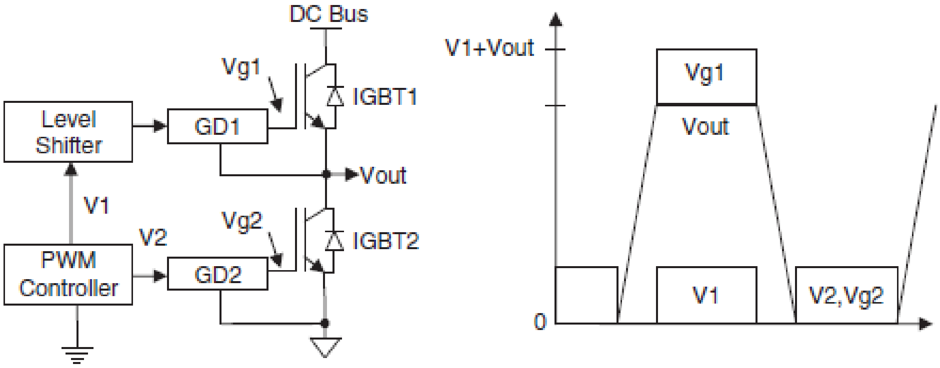

Figure 4: The concept of level shifting and the placement of the switching control signal on top of the inverter output voltage.

(a) **Transformer Level Shifting:**The obvious solution for delivering a level-shifted signal is a transformer. Compared to opto-couplers, they have high noise immunity. Level shifting transformers also offer the advantage of giving the power semiconductor switch (Figure. 5) both the gate drive and control power signal, so removing. This does away with the requirement for a floating power source. Careful transformer design must be used when operating at high switching frequencies, above several hundred kilohertz, in order to prevent the negative consequences of transformer leakage inductance. When huge currents are needed to drive gates quickly, the transformer gate driver has another constraint. The parasitic transformer components start to have a big impact. The transformer turns are typically minimised in an effort to deliver high peak currents at quick rise and fall times, which has other limits on transformer design. It is occasionally preferable to use a specialised low impedance output MOS-gate driver with a floating power supply and just transmit the low power control signal via a transformer in cases of high speed and high current delivery in order to prevent degradation of the gate drive waveform. The average volt-time product across any winding must be zero, which makes it impossible for the gate drive transformer to transmit DC information and limits its ability to operate. The gate drive capacitor will remove the DC offset from the signal when a high duty cycle is demanded, which may lead to operation below the device threshold voltage Vge(th). The device won't turn on or even function in the linear zone as a result of this circumstance. As a result, there is significant semiconductor power loss [5]–[7].

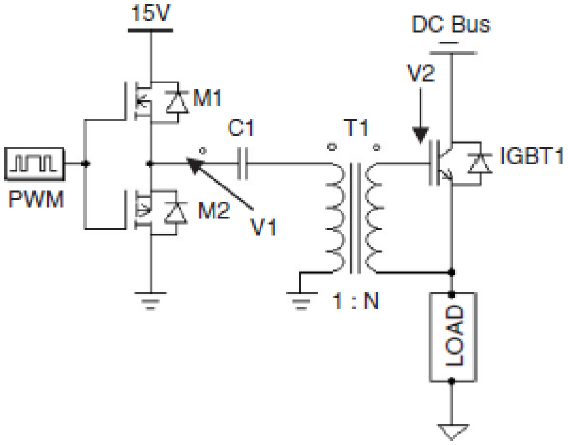

Figure 5: Combined Transformer Level Shifter and Gate Driver.

(b) Optical Level Shifting – Opto-couplers:

Optical isolation is another technique used for achieving level shifting. However, the trade-off is that the receiver end of the system now needs a separate floating supply. Interface for gate drivers although they are simple and inexpensive, opto-couplers are prone to noise and rapid voltage changes. This is frequent in gate drive circuits. This requirement creates extra stress on the power supply filtering and PCB architecture surrounding the opto-coupler in order to achieve reliable functioning. The tiny footprint (6-8 pin dual in line or surface mount package), output enable pin, and compatibility with any logic level input due to its current-driven (an input diode) input are further advantages of opto-coupler technology. Opto-couplers with a wide range of operating speeds up to 15 MBd, rise and fall times of 10–20 ns, and noise immunity levels (dv/dt rating) of 10-15 V/ns are readily available commercially. Given that the breakdown voltages of the majority of semiconductors are lower than this, typical opto-coupler isolation voltages in the range of 5 kV are sufficient.

(c) Optical Level Shifting – Fiber Optic Link:

Electromagnetic fields can affect electrical conductors, which causes them to emit and absorb electromagnetic noise. Fibre optic links move through loud environments undisturbed since they don't emit or receive electromagnetic noise. Additionally, ground noise can become an issue when working with currents that are changing very quickly. Any ground loop or common-mode noise issues are virtually eliminated by a fibre optic link. Figure. 6 depicts a fundamental fibre optic communication system.The PWM drive signal powers the LED. A section of fibre optic cable carries the LED's light output to the receiver. The receiver includes a PIN. Trans-impedance amplifier and a photodiode. A comparator level-identifies the amplifier's output voltage and turns it into a logic signal. By simply stretching the fibre optic cable, the galvanic isolation and dv/dt rating of this communication link can be raised to practically any desired value. The isolation voltage for a modest length of 10 cm of fibre optic cable is about 100 kV. Even the highest realisable dv/dt rating will have minimal impact because the coupling capacitance is almost nil, despite how difficult it is to compute the dv/dt rating. The fibre optics systems' bandwidth enables operation at frequencies greater than 1 GHz.

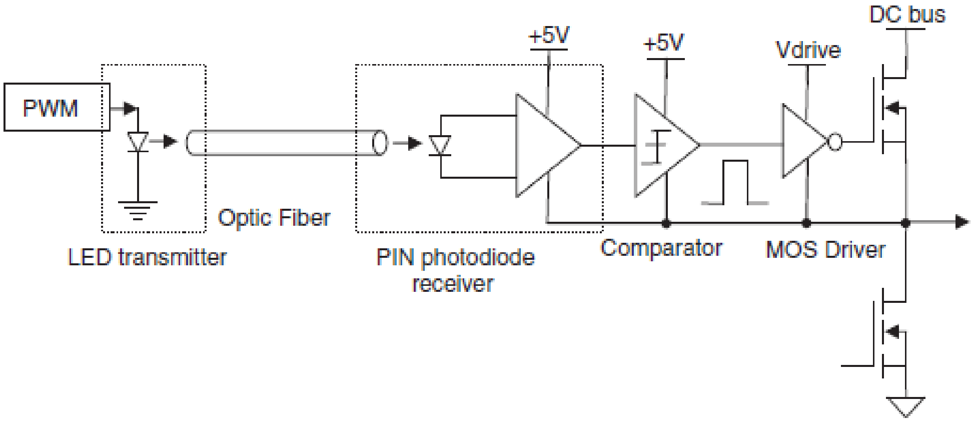

Figure 6: Fiber optic level shifting circuit used for high speed, extremely high noise immunity, and very high isolation voltage capability

(d) Electronic Level Shifting:

The idea behind how electronic level shifters operate is that a current source is referenced to a fixed potential. They are also known as common source level shifters since the low-side switch source often serves as their reference potential. Regardless of the voltage across a current source, the driving signal causes a specific current to be drawn through it. The receiving side detects the current and converts it into on/off information. Electronic level shifters don't offer isolation, but they can be incorporated onto a single chip because they are an entirely electronic solution.

Applications of gate drivers: Gate drivers are frequently utilised in numerous power electronic system applications where high efficiency, high power density, and quick switching speed are necessary. Gate drivers are used in a variety of applications, such as:

1. Gate drivers are crucial parts of motor drives, which are used to regulate the direction and speed of electric motors. The power transistors that switch the current to the motor windings are driven in motor drives using gate drivers. Electric motors can be used in a variety of applications because the motor drive can adjust the timing and length of these switching events, which in turn controls the motor speed and torque.
2. Gate drivers are additionally utilised in power supplies, which are devices that change one type of electrical energy into another. Gate drivers are employed in switch-mode power supplies to manage the switching of the power transistors that control the output voltage or current. Power supplies, which are utilised in several applications including consumer electronics, telecommunications, and industrial automation, can now be designed with great efficiency and compactness.

3. Gate drivers are used in solar inverters, which change the DC voltage generated by solar panels into AC voltage that can be used by the electrical grid, in solar photovoltaic (PV) systems. Gate drivers are employed in solar inverters to manage the switching of the power transistors that control the inverter's output voltage and frequency. The solar PV system can operate with high efficiency and dependability as a result.
4. In electric vehicles (EVs), which use power electronic systems to regulate the motor speed and battery charge, gate drivers are also utilised. The power transistors in EVs that switch the current to the electric motor are driven by gate drivers. This enhances the performance and range of the EV by enabling effective and accurate regulation of the motor speed and torque.
5. Gate drivers are utilised in wind power systems' wind turbine generators (WTGs), which transform wind's mechanical energy into electrical energy. Gate drivers are used in WTGs to govern the switching of the power transistors that control the generator's output voltage and frequency. This enables the WTG, which can produce a sizable quantity of renewable energy, to operate efficiently and dependably.

Gate drivers are also utilised in numerous other power electronic systems, including welding equipment, uninterruptible power supplies (UPS), and high-frequency induction heating, in addition to these uses. Gate drivers are essential to the effective, dependable, and secure operation of the power electronic system in each of these applications.

Advantages and disadvantages of gate drivers: In power electronic systems that need quick switching times and high power densities, gate drivers are crucial components. Power electronic systems must take into account some drawbacks in addition to their many benefits when designing and implementing them.

Benefits of gate operators:

a) **Faster Switching Rates:**Power transistors can switch on and off quickly because gate drivers supply the necessary voltage and current to the transistor's gate. Faster switching rates are produced as a result, which is crucial for high-frequency applications that call for effective power conversion.
b) **Greater Efficiency:**Gate drivers can increase the overall efficiency of power electronic systems by enabling quick and accurate control of the power transistors. This lessens energy losses and may help the power electronic system last longer.
c) **Increased Power Density:**By enabling more compact and smaller designs, gate drivers can aid in enhancing the power density of power electronic systems. This is crucial in applications with constrained space, including portable electronics and electric cars.
d) **Increased Dependability:**By offering overcurrent protection, overvoltage protection, and other safety features, gate drivers can contribute to increasing the dependability of power electronic systems. This can prolong the lifespan of the power electronic system and prevent damage.
e) Gate drivers can be made to fit the requirements of a given application thanks to their customizable design. This enables a high degree of customization and may lead to improved productivity.

Drawbacks of gate operators:

a) **Complexity:** The design and implementation of gate drivers can be complicated and call for specialised knowledge. The power electronic system may become more expensive to operate and repair as a result.

b) **Cost:** In comparison to other parts of a power electronic system, gate drivers can be quite pricey. This may raise the system's overall cost, which might make it harder for some applications to adopt it.
c) **Dissipation of heat:** In order to keep the power electronic system from being harmed, gate drivers can produce a lot of heat. As a result, the system's overall size and cost may grow and extra cooling components may be needed.
d) Gate drivers have the potential to produce electromagnetic interference (EMI), which can affect the functioning of other electrical equipment. While this can be reduced with the right shielding and filtering, it can complicate and increase the cost of the power electronic system's design.
e) **Gate charge loss:** When gate drivers experience a loss of gate charge, switching times are likely to slow down and their efficiency may be compromised. This can be overcome by carefully choosing the gate driver and power transistor components, but it can make the design process more difficult.

Gate drivers have a variety of benefits for power electronic systems, including greater switching speed, efficiency, power density, dependability, and design flexibility. They do, however, have a few drawbacks, including complexity, price, and heat dissipation, EMI, and gate charge loss. When designing and executing power electronic systems that use gate drivers, these aspects must be taken into account [8], [9].

CONCLUSION

In conclusion, gate drive circuitry is an essential part of power electronics systems that guarantees the efficient and dependable operation of power semiconductor devices. The effectiveness and dependability of a system may be greatly impacted by the right design and execution of gate drive circuits, therefore designers must carefully take important factors like voltage and current ratings, switching speed, and protective features into account. New gate drive circuit topologies and components are emerging as power electronics technology progresses, giving enhanced performance and efficiency.

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CHAPTER 14

A BRIEF DISCUSSION ON CAPACITOR CHARGING APPLICATIONS

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ABSTRACT:

Electronics require the process of capacitor charging, which includes applying a voltage to a capacitor in order to store electrical energy in it. A passive electronic component known as a capacitor has the ability to store energy in an electric field that exists between two conducting plates. Capacitor charging is a crucial operation in many electrical devices and systems. In this procedure, a capacitor stores electrical energy by having a voltage applied to it. Applications for capacitor charging include voltage management, power filtering, and energy storage. The various uses of capacitor charging and their significance in various electrical systems are covered in this chapter.

KEYWORDS:

Capacitor Charging, Electronic System, Energy Store, Power Filtering, Voltage Regulating.

INTRODUCTION

Electronics require the process of capacitor charging, which includes applying a voltage to a capacitor in order to store electrical energy in it. A passive electronic component known as a capacitor has the ability to store energy in an electric field that exists between two conducting plates. A capacitor charges to the applied voltage when a voltage is applied, and it also stores energy in its electric field. Energy storage, power filtering, voltage regulation, and timing circuits are just a few uses for capacitors. Capacitors are used in the energy storage application to store energy that may subsequently be released to power devices. Capacitors are frequently employed in applications where a little amount of energy is needed, such as in camera flashes, electronic toys, and strobe lights. Capacitors can store energy for brief periods. Because capacitors can swiftly release their energy, they are appropriate for applications that call for a sudden surge of power. Capacitors are utilised in the power filtering application to filter out undesired frequencies from the power source. A capacitor charges up when a voltage is provided, which induces current in the circuit. The power supply's high-frequency noise or ripple can be filtered out using this current. Capacitors help smooth the power supply output and lessen noise and ripple in the voltage output [1]–[3].

Capacitors are utilised in the voltage regulation application to stabilise the voltage and avoid voltage spikes. When a capacitor is attached to a power source, it functions as a buffer to take care of input voltage spikes and dips. Voltage regulators can make use of capacitors to keep the output voltage steady even while the input voltage varies. Capacitors are used to regulate the time of electronic circuits in timing circuit applications. To add a time delay to a circuit, capacitors and resistors can be combined. A capacitor charges to the applied voltage when a voltage is applied to it. The capacitor discharges through a resistor after the voltage is turned off, which causes a temporal delay. Applications for capacitors include pulse generators, timers, and oscillators. Understanding the process of capacitor charging is critical for creating effective and dependable electronic devices. Capacitors are a vital component of contemporary electronics and are utilised widely in electronic devices, from straightforward circuits to intricate systems. Modern capacitors are more compact, dependable, and efficient than earlier models because to advancements in capacitor technology. There are several uses for the crucial electronic process known as capacitor charging. Capacitors have many useful functions, including energy storage, frequency filtering, voltage stabilisation, and time control for electronic circuits. Electronic devices frequently use capacitors, thus it's important to understand how capacitor charging works in order to design dependable and efficient electronics.

Conventional dc power supplies work with a load that is constant or nearly constant at a particular dc output voltage. However, pulse loads like lasers, flashlamps, railguns, and radar need quick but powerful energy bursts. Typically, this energy is first released into the load after being held in a capacitor. The repetition rate, T, is the rate at which the capacitor is charged and discharged. It can range from 0.01 Hz for large capacitor banks to a few kHz for some lasers. A capacitor charging power supply (CCPS) is responsible for recharging the capacitor voltage to the required voltage. This chapter discusses the function of power electronics components, topologies, and charging methods for capacitor charging applications.

The voltage across the energy storage capacitor attached to a CCPS output is shown in Figure 1. This diagram illustrates the three operational modes of the CCPS. The capacitor is charged in the first mode, which is the charging mode, from a zero initial voltage to a predetermined final value. The energy storage capacitor's capacitance and the rate of the CCPS's energy delivery define how long the charging mode lasts. The refresh mode, which could be compared to a "standby mode," is the next mode of operation. In this mode, the energy that has been saved is only preserved. The CCPS should activate and provide the energy required to account for capacitor leakage once the output voltage falls below a set threshold. The refresh phase should last as little time as feasible because energy is lost during it.

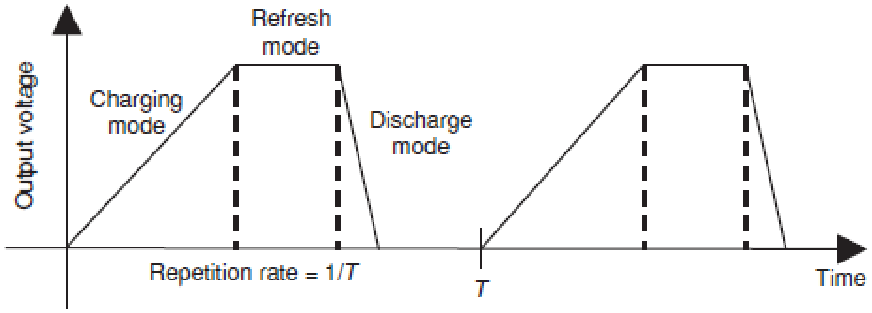

Figure 1: Three modes of operation of a capacitor charging power supply

Safety margins for worst-case charging and discharging mode timings and switching device SOA requirements are problems that result in nonzero refresh times. The load is actively discharging the capacitor in the discharge mode, which is the last mode of operation. In this mode, the CCPS doesn't provide any energy to the load. How quickly the load can discharge the capacitor determines how long the CCPS stays in this mode.

In contrast to a traditional dc power supply, which delivers a nearly constant power to its load, a CCPS's instantaneous output power ranges widely. The output power for the pulsed power load is depicted as linear for illustration only in Figure 2. High peak power is a defining feature of the charging mode. The output power is zero at the start of this mode (current is flowing but there is no voltage). As a result, a short circuit is the same as the load capacitor. Additionally, the output power is zero at the conclusion of the charging phase (i.e., there is an output voltage present but no current is flowing). The load capacitor now resembles an open circuit. Due to the minimal current needed to account for capacitor leakage, the refresh mode is often a low-power mode. When the energy storage capacitor is being discharged by the pulsed load while in the discharge mode, the CCPS does not provide any power [4], [5].

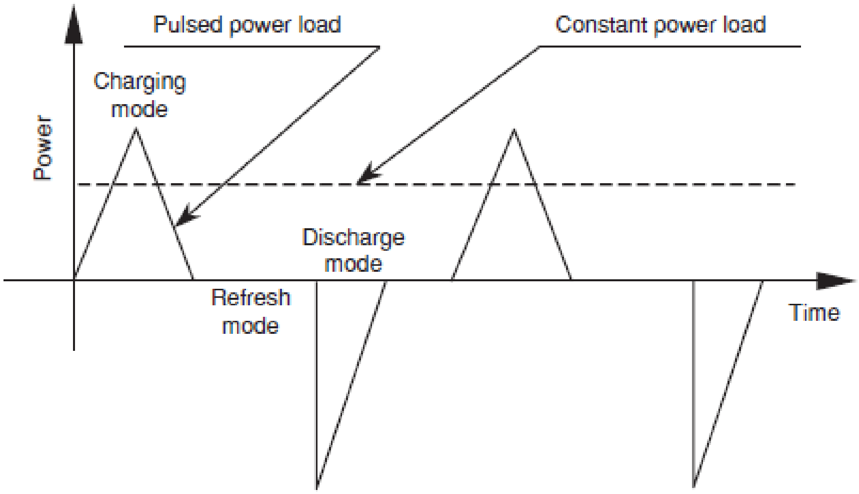

Figure 2: Power requirements for pulsed power and constant power loads.

The discharge mode energy and load repetition rate affect a CCPS's average output power. It reaches its maximum when the energy storage capacitor discharges (high voltage and current) at the conclusion of the charging mode, which equates to operation without a refresh mode. The rating of a CCPS is frequently reported in kJ/s rather than kW because the CCPS power is not consistent.The kJ/s rating can be written as

$$\mathrm{kJ/s} = W_{LOAD}\, T$$

Where W_{LOAD} is the energy delivered to the load per charging refresh and instantaneous discharge, the kJ/s rating is limited to how fast a particular capacitor can be charged by its specified voltage. T is the repetition rate, and cycle. In the optimum case with no refresh and instantaneous discharge, the kJ/s rating is limited to how fast a particular capacitor can be charged by its specified voltage.

DISCUSSION

High-Voltage DC Power Supply with Charging Resistor: In this method, as shown in Figure. 3, a high-voltage dc power supply charges the energy storage capacitor through a charging resistor. The charging mode ends when the capacitor voltage equals the output voltage of the power supply. The power supply continuously recharges the capacitor. The charging resistor separates the power supply from the pulse load during discharge mode. This method's benefits are its ease of use, dependability, and affordability. The major disadvantage of this technique is its poor efficiency.

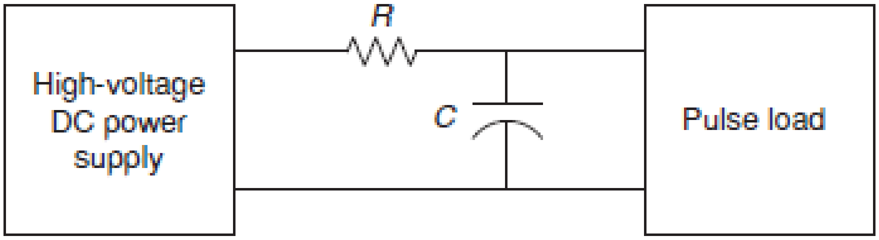

Figure 3: High-voltage dc power supply and charging resistor

In the charging mode, the energy dissipated in the charging resistor is equal to the energy stored in the capacitor in the ideal case; therefore, the maximum efficiency is 50%. As a result, this approach is applied primarily in situations where the charge rate is minimal, i.e. 200 J/s. The charging time, which is governed by the RC time constant, is another drawback of this method. The output voltage must match the target voltage to within 0.1% for some laser applications. For this method, the capacitor voltage must exceed this voltage specification by more than five time constants [6]–[8].

Switching Converters: Its use is restricted to low charging rates because to the poor efficiency when charging a capacitor through a resistor from a high-voltage power supply. There is no way to account for capacitor leakage in the resonance-charging concepts since energy is transmitted to the load capacitor in a single pulse.

The same power electronic technology used in switching converters for constant power loads can be used to charge energy storage capacitors. Switching converters provide the ability to charge the energy storage capacitor with a pulse train, as opposed to a single pulse. When charging in a sequence of pulses, the peak current is decreased, increasing the charging process' effectiveness. The switching converter's efficiency may also be improved by using soft-switching methods. The pulse train's ability to transfer energy to the energy storage capacitor in discrete packets improves the regulation of the output voltage. The size of the energy packet can be managed using common control methods like pulse width modulation. The CCPS can work in the refresh mode and account for capacitor leakage thanks to its capacity to regulate the size of the energy packet. The CCPS may therefore function at a wide range of load repetition rates while still maintaining precise output voltage regulation while in refresh mode. Energy lost due to capacitor leakage may be replenished in the refresh mode either in a burst of energy or continuously, much like trickle charging a battery.

To enable the usage of MOSFETs or IGBTs in the CCPS, semiconductor switches in the switching converter may be operated on the transformer's lower side. The switching converter must be able to function under this extreme load level since the CCPS starts the charging mode with a short circuit across its output. A current-limiting system may need to be implemented in the converter control circuit to achieve this. A switching converter is made up of a resonant converter, as seen in Figure 4. Keep in mind that the low-voltage side of the transformer is where the MOSFETs and resonant elements Lr and Cr are attached. Only the energy storage capacitor and rectifier diodes require high voltage ratings. The energy storage capacitor C1 is connected in series with the resonant capacitor Cr when the output rectifier is conducting.

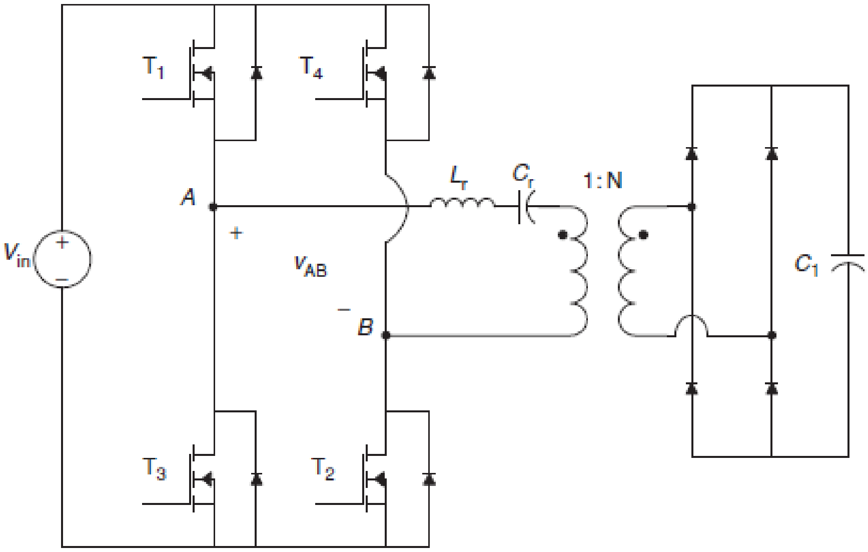

Figure 4: Series resonant converter.

Need of capacitor charging: The proper operation of electronic systems and gadgets depends on the fundamental electronic process of capacitor charging. Capacitors are inert electronic parts that have electric fields that can store electrical energy. An energy is charged and stored in a capacitor when a voltage is applied. Electronics uses for capacitor charging range from energy storage to power filtering, voltage management, and timing circuits.

Energy storage is one of the main requirements for capacitor charging. Capacitors are appropriate for applications that call for a sudden burst of power because they can store energy for brief periods of time and release it fast. Additionally, capacitors have a greater capacity for energy storage than batteries, which is crucial for portable electronic gadgets. Electronic toys, strobe lights, camera flashes, and other devices that call for a quick yet powerful release of energy can all benefit from the employment of capacitors. Power filtering is an additional requirement for capacitor charging. Capacitors help smooth the power supply output and lessen noise and ripple in the voltage output. Filters can be made using capacitors, resistors, and inductors to remove undesirable frequencies from the power supply. For many electronic devices, power filtering is crucial since noise and ripple can impair the device's functionality.

Voltage regulation also requires capacitance recharging. Voltage spikes can be avoided and the voltage can be stabilised via capacitors. When a capacitor is attached to a power source, it functions as a buffer to take care of input voltage spikes and dips. Voltage regulators can make use of capacitors to keep the output voltage steady even while the input voltage varies. Many electronic devices require voltage management because variations in voltage can harm or disrupt the equipment. Timing circuits also require capacitor charging. To add a time delay to a circuit, capacitors and resistors can be combined. A capacitor charges to the applied voltage when a voltage is applied to it. The capacitor discharges through a resistor after the voltage is turned off, which causes a temporal delay. Applications for capacitors include pulse generators, timers, and oscillators. Many electrical devices require timing circuits because they regulate the order in which events occur.

Capacitor charging is necessary for electronic circuit operation in addition to these particular uses. Capacitors are frequently employed to separate signals, disconnect power supply, and provide coupling between several stages of a circuit. It is essential to charge the capacitors to make sure that these tasks are completed properly. Electronics' crucial process of capacitor charging is required for a wide range of applications. Energy may be stored in capacitors, which can also filter out undesired frequencies, stabilise voltages, regulate the timing of electrical circuits, and carry out a variety of other tasks. Understanding the applications of capacitor charging is critical for creating effective and dependable electronic devices. Capacitor charging is necessary for the proper operation of electronic devices.

Applications of capacitor charging: Electronics' fundamental process of capacitor charging offers a wide range of real-world uses. Capacitors are inert electronic parts that have electric fields that can store electrical energy. An energy is charged and stored in a capacitor when a voltage is applied. Electronics uses for capacitor charging range from energy storage to power filtering, voltage management, and timing circuits. Energy storage is one of the main uses for capacitor charging. Capacitors are appropriate for applications that call for a sudden burst of power because they can store energy for brief periods of time and release it fast. Electronic toys, strobe lights, camera flashes, and other devices that call for a quick yet powerful release of energy can all benefit from the employment of capacitors.

Power filtering is another use for capacitor charging. Capacitors help smooth the power supply output and lessen noise and ripple in the voltage output. Filters can be made using capacitors, resistors, and inductors to remove undesirable frequencies from the power supply. For many electronic devices, power filtering is crucial since noise and ripple can impair the device's functionality. Voltage regulation also uses capacitor charging. Voltage spikes can be avoided and the voltage can be stabilised via capacitors. When a capacitor is attached to a power source, it functions as a buffer to take care of input voltage spikes and dips. Voltage regulators can make use of capacitors to keep the output voltage steady even while the input voltage varies. Many electronic devices require voltage management because variations in voltage can harm or disrupt the equipment.

Timing circuits also employ capacitor charging. To add a time delay to a circuit, capacitors and resistors can be combined. A capacitor charges to the applied voltage when a voltage is applied to it. The capacitor discharges through a resistor after the voltage is turned off, which causes a temporal delay. Applications for capacitors include pulse generators, timers, and oscillators. Many electrical devices require timing circuits because they regulate the order in which events occur. Both electric and hybrid electric vehicles (HEVs) use capacitor charging as a form of energy storage. The capacitor's energy can be used to power the electric motor of the car or to add extra power for accelerating. Additionally, capacitors can be utilised in regenerative braking systems, which use the energy produced during braking to power the vehicle during acceleration.

Audio applications also make advantage of capacitor charging. Filters that exclude undesirable frequencies from audio signals can be made by combining capacitors and resistors. In order to ensure that the audio signal is amplified properly and that the various stages of the amplifier do not interfere with one another, capacitors can also be employed to link the audio signal between the various stages of an amplifier circuit. Capacitor charging is utilised in a wide variety of other electronic applications, such as power supplies, lighting circuits, computer circuits, and telecommunications systems.

Advantage of capacitor charging: The process of charging capacitors is useful in electronics because it provides a number of benefits. The following are some of the main benefits of capacitor charging:

a) Capacitors are very effective at storing electrical energy. They are perfect for applications that need a fast burst of power since they can store energy for brief periods of time and discharge it quickly.
b) High power density: Capacitors can store a lot of energy in a little amount of space thanks to their high power density. They are therefore perfect for use in portable electronics and other applications with limited space.
c) Low maintenance: Capacitors are generally straightforward parts that need little upkeep. They don't have any moving parts, thus they don't deteriorate with time like other parts, like batteries.
d) Lengthy lifespan: When compared to other electronic components, capacitors have a lengthy lifespan. They can survive for many years, and unlike batteries, they do not lose performance with time.
e) Capacitors are perfect for applications that call for a short response time since they can charge and discharge quickly.
f) Regulation of voltage: Capacitors can maintain a steady voltage and avoid voltage peaks. This is crucial to guaranteeing the device's correct operation and safeguarding delicate electrical components from harm.
g) Low cost: Capacitors are an appealing alternative for many applications since they are relatively inexpensive when compared to other electronic components.

Generally, capacitor charging is a flexible process with numerous benefits in electronics. In addition to being very good at storing energy, capacitors also offer a high power density, a long lifespan, few maintenance requirements, charge and discharge quickly, stabilise voltage, and are inexpensive. It's critical to comprehend the benefits of capacitor charging while creating dependable and effective electronic gadgets.

Disadvantage of capacitor charging: Although capacitor charging has a number of benefits, there are a few drawbacks to take into account. The following are some of the key drawbacks of charging capacitors:

a) Capacitors' storage capacity is constrained when compared to that of batteries and other energy storage technologies. They cannot be used for applications that call for long-term energy storage, therefore.
b) **Voltage limitations:** Capacitors can only store a certain amount of voltage due to their voltage constraint. The capacitor may be damaged or possibly fail if the voltage is higher than the voltage rating.
c) **Temperature sensitivity:** Capacitors are susceptible to temperature variations. The longevity and general functionality of the capacitor can be impacted by the performance of the capacitor degrading under extreme temperatures.
d) Capacitors have a restricted operating temperature range, and if they are used outside of this range, their performance may degrade. The capacitor may break down or malfunction in extremely hot or cold conditions.
e) **Cost:** High-capacity capacitors can be pricey, which may make them less desirable for particular applications even though they are often less expensive than batteries and other energy storage technologies.
f) **Environmental issues:** If capacitors are not disposed of appropriately, the compounds they contain may be detrimental to the environment. Electrolytic capacitors, which include hazardous materials like beryllium and aluminium, are a good example of this.

Although capacitor charging in electronics provides many benefits, there are certain drawbacks to take into account. Voltage restrictions, limited storage capacity, and sensitivity to temperature changes are all characteristics of capacitors. Additionally, they may be pricey, have a restricted operating temperature range, or include environmentally hazardous components. It's critical to comprehend the drawbacks of capacitor charging while creating effective and environmentally friendly electronic equipment [9], [10].

CONCLUSION

There are several uses for the fundamental electronic process known as capacitor charging. Capacitors are used in energy storage to store energy that can subsequently be released to power electronics. Capacitors are used in power filtering to remove undesirable frequencies from the power source. Capacitors are used in voltage regulation to maintain the voltage and avoid voltage spikes. Understanding the applications of capacitor charging is critical for creating effective and dependable electronic devices. Capacitor charging is necessary for the proper operation of electronic systems.

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CHAPTER 15

STUDY ON ELECTRONIC BALLAST THEORY

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ABSTRACT:

The electrical current that passes through fluorescent bulbs is controlled by an electronic ballast. An overview of the theory underlying electronic ballasts and their advantages over conventional electromagnetic ballasts are given in this chapter. The many kinds of electronic ballasts, their working theories, and their applications are also covered in the study. Finally, this chapter draws attention to the advantages of adopting electronic ballasts.

KEYWORDS:

Current Regulation, Discharge Lamps, Electronic Ballast, Electromagnetic Ballast, Fluorescent Lamps.

INTRODUCTION

These power electronic converters used to supply discharge lamps are known as electronic ballasts, also known as solid-state ballasts. With the development of power bipolar transistors with short storage times, fluorescent lamps could be powered at frequencies of several kilohertz, boosting the luminous efficacy of the lamps. This was the beginning of the contemporary era of electronic ballasts. With the later development of low-cost power MOSFETs, which have distinct qualities that make them particularly desirable to implement solid-state ballasts, electronic ballasts rose to great popularity. The main advantages of electronic ballasts are an improvement in lighting quality, an increase in lamp life, a decrease in ballast size and weight, and an increase in overall lamp and ballast efficiency. This chapter aims to provide a broad overview of the key issues surrounding this category of power converters [1]–[3].

Electronic ballasts are used to control the electrical current that passes through fluorescent bulbs. They were created as a replacement for conventional electromagnetic ballasts, which are infamous for their poor efficiency and short lamp life. Electronic ballasts are made to increase the longevity and energy efficiency of fluorescent lighting while lowering flicker and enhancing colour rendering. A ballast's main job is to control the electrical current that passes through a fluorescent lamp. Once lit, fluorescent lamps need a lower voltage to keep the current flowing; yet, they need a high voltage to start. Ballasts are in charge of supplying the required voltage to turn on the lamp and then controlling the current flow to keep it operating at its brightest and most efficient. When compared to electromagnetic ballasts, electronic ballasts operate differently. To change the input AC voltage to DC voltage, they employ electronic components like transistors and capacitors. The lamp current is then controlled by converting the DC voltage back to high-frequency AC voltage. Electronic ballasts are able to operate more effectively and with less heat loss because they run at considerably higher frequencies than electromagnetic ballasts, often in the 20 kHz to 60 kHz range.

The improved effectiveness of electronic ballasts is one of its main advantages. Traditional electromagnetic ballasts can be up to 30% less efficient than electronic ballasts. Less energy is consumed as a result of the greater efficiency, which can ultimately result in significant cost savings. In addition to producing less heat than electromagnetic ballasts, electronic ballasts can help cut the cost of cooling in commercial and industrial environments. The longer bulb life of electronic ballasts is another advantage. Higher frequency operation of electronic ballasts results in less strain on light filaments. As a result, the bulb has a longer lifespan, which can save maintenance costs and raise the lighting system's general efficiency.

Additionally, electronic ballasts provide less flicker and better colour rendering. The harsh, chilly light that traditional fluorescent bulbs are known to produce can be unattractive to many skin tones and colours. Fluorescent lamps' colour rendering can be enhanced with electronic ballasts, which makes them more suitable for spaces where colour accuracy is crucial, like retail settings or art studios. Furthermore, electronic ballasts help lessen traditional fluorescent lamps' flicker, which in some people can result in headaches and eye strain. Electronic ballasts come in two primary categories: passive and active. A resonant circuit is used by passive ballasts to control how much current flows into the light. A power factor adjustment circuit is used by active ballasts to increase energy effectiveness. Compared to active ballasts, passive ballasts are less expensive and easier to make, but they are less efficient and could generate more heat.

In industrial, commercial, and residential contexts, electronic ballasts are frequently employed. They are particularly used in large buildings, including offices and warehouses, where the cost of lighting can be high. In household settings, where they can lower energy costs and lengthen the lifespan of fluorescent lamps, electronic ballasts are also well-liked. A crucial part of contemporary lighting systems are electronic ballasts. In comparison to conventional electromagnetic ballasts, they have a number of benefits, such as greater efficiency, a longer lamp life, better colour rendering, and less flicker. Due to their energy efficiency and low maintenance requirements, electronic ballasts are frequently utilised in residential, commercial, and industrial applications. Electronic ballasts will remain a crucial component of the lighting sector as long as there is a desire for energy-efficient lighting solutions.

Need of Electronic Ballast: Electronic ballasts are required for a number of factors, including:

a) **Energy Efficiency:** Compared to conventional electromagnetic ballasts, electronic ballasts are more energy efficient. The cost of cooling is decreased since they use less energy and emit less heat. Over time, this improved efficiency may result in significant cost savings.
b) Electronic ballasts contribute to fluorescent lamps' longer lamp lives. The filaments in the lamps endure less damage since they work at higher frequencies. As a result, the bulb has a longer lifespan, which can save maintenance costs and raise the lighting system's general efficiency.
c) An improvement in colour rendering is made possible by the fact that conventional fluorescent bulbs are notorious for their harsh, cool lighting, which can be unflattering to different skin tones and colours. Fluorescent lamps' colour rendering can be enhanced with electronic ballasts, which makes them more suitable for spaces where colour accuracy is crucial, like retail settings or art studios.
d) **Reduced Flicker:** Electronic ballasts can lessen the classic fluorescent bulbs' flicker, which in some people can cause headaches and eye strain.

e) **Noise reduction:** Compared to electromagnetic ballasts, electronic ballasts are less noisy, which can be particularly crucial in residential contexts.
f) **Flexibility:** In terms of dimming and control options, electronic ballasts provide additional flexibility. They are simple to incorporate into automatic lighting systems, which may result in further energy savings.

Overall, electronic ballasts are required to increase the performance and energy effectiveness of fluorescent lighting. They have many advantages over conventional electromagnetic ballasts, including enhanced colour rendering, lower flicker, and reduced noise. Electronic ballasts will remain a crucial component of the lighting sector as long as there is a desire for energy-efficient lighting solutions.

Drawbacks of electronic ballast:

1. **Higher Initial Cost:** Compared to conventional electromagnetic ballasts, electronic ballasts are more expensive, which may be a drawback for individuals or organisations on a tight budget.
2. **Issues with Compatibility:** Not all fluorescent light types are compatible with all electrical ballasts. Before buying an electronic ballast, it is crucial to confirm compatibility.
3. **Electronic Interference:** Electromagnetic interference from electronic ballasts can interfere with nearby electronics. In some environments, like hospitals or research centres, this might be a problem.
4. **Failure Rate:** Compared to conventional electromagnetic ballasts, electronic ballasts could have a higher failure rate. Over time, this may lead to higher maintenance costs.
5. **Environmental Impact:** If improperly disposed of, dangerous substances like lead or mercury can harm the environment. Electronic ballasts may contain these substances.

Overall, electronic ballasts provide a number of benefits over conventional electromagnetic ballasts, including greater colour rendering, longer bulb life, less flicker, and less noise. However, there are also several drawbacks that should be taken into account when determining whether to employ electronic ballasts in a lighting system, including higher initial cost, compatibility problems, electronic interference, and environmental effect [4], [5].

DISCUSSION

Discharge Lamps: Discharge lamps essentially consist of a discharge tube where electromagnetic radiation is created from electric energy. According to Figure 1, the discharge tube is constructed from a transparent or translucent material and has two sealed-in electrodes positioned at either end. An inert gas and a metal vapour are both present in the discharge tube. The discharge's electrical field accelerates the free electrons that are produced by the electrodes. Depending on the electron kinetic energy, these accelerated electrons smash with the gas atoms in both elastic and inelastic ways. In Fig. 1, the fundamental operations taking place inside the discharge tube are depicted.

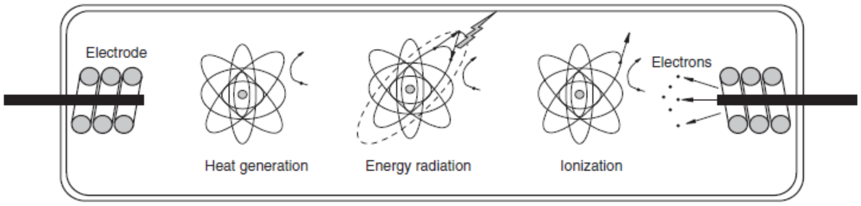

Figure 1: Basic processes inside the discharge tube.

Heat generation: Low electron kinetic energy results in an elastic collision, which only transfers a small portion of the electron's energy to the gas atom. The temperature of the gas rises as a result of these encounters. In this instance, heat dissipation is produced by consuming electrical energy. The discharge must set in at its ideal operating temperature, thus this is also a crucial process.

Gas atom Excitation: Due to some electrons have high kinetic energies, the energy from the impact can be used to move a gas atom's electron to a higher orbit. The electron tends to return to its initial level in this unstable state, producing electromagnetic radiation made up of the absorbed energy. This radiation is utilised to create visible light directly, or in another scenario, ultraviolet light is first produced and then converted to visible light using a phosphor coating present on the discharge tube's inner wall.

Gas atom Ionization: Sometimes, when an electron collides with a gas atom, it has gathered such high kinetic energy that it liberates an electron from the gas atom, creating a positively charged ion and a free electron. The roles that the electrode-generated electrons can play are also available to this released electron. Ionised atoms and electrons are required to maintain the electrical current through the lamp during both discharge ignition and normal operation, making this process especially crucial at both of these times. Due to continued ionisation, the discharge's free electron count may rise quickly, leading to an infinite current and eventually a short circuit [6]–[8].

Low-Pressure Discharge Lamps: Low current density and low power per unit of discharge length are features of this type of lamp, which operates at pressures of roughly 1 Pa. As a result, these lamps often have a fairly large discharge volume and a low power rating. Low-pressure mercury lamps, sometimes referred to as fluorescent and low-pressure sodium lamps, are the most typical examples.

High-Pressure Discharge Lamps: In order to significantly boost the luminous efficacy of the discharge, this type of lamp's operating pressure is typically 105 Pa or more. These lamps exhibit a high power to discharge length ratio and a high current density in the discharge, resulting in significantly smaller discharge tubes. High-pressure mercury, sodium, and metal halide lamps are a few examples of these lamps. Finally, understanding the correlated colour temperature (CCT) and the colour rendering index (CRI) is essential in order to describe the light emitted by a discharge lamp. The temperature of the blackbody radiator whose perceived colour is closest to that of the discharge lamp is known as the CCT. As the temperature increases, an incandescent body's colour shifts from deep red to orange, yellow, and finally white. Therefore, a high-pressure sodium lamp has a CCT of about 2000 K and seems to be yellow, whereas a cool white fluorescent lamp has a CCT of about 3500 K and is regarded as a white source of light. When compared to how the same things would seem under a reference source with an identical CCT, the CRI of a light source measures its impact on the colour appearance of the objects it illuminates. The measurement yields a result that is less than 100, and the greater the CRI, the more accurate the colour reproduction. For instance, the CRI of daylight and incandescent lighting is 100.

Fluorescent Lamps: These lights fall within the low-pressure mercury vapour discharge lamp group. The discharge produces weak lines in the visible region of the spectrum as well as two prominent lines at 185 and 253.7 nm. The ultraviolet light is transformed into visible light by a fluorescent powder on the discharge tube's inside wall, producing a broad spectrum distribution and accurate colour reproduction. The ideal mercury vapour pressure for these lamps, which provides the greatest luminous efficacy, is 0.8 Pa. This pressure is obtained for the commonly used tube diameters at a wall temperature of roughly 40 °C, which is not significantly higher than the usual ambient temperature. Without the use of an exterior bulb, the heat produced inside the discharge is sufficient to reach the necessary working temperature. However, one significant disadvantage of fluorescent lamps is that this structure results in a significant change of lamp lumen output with temperature. The inclusion of amalgams to stabilise the light output is one solution to this issue. Particularly in tiny fluorescent bulbs, this is employed.

Low-Pressure Sodium Lamps: The most effective source of light is a bulb like this. The radiation they produce is virtually monochromatic, with two main lines at 589 and 589.6 nm, which is quite close to the threshold of human vision. Therefore, these lamps' colour rendering is quite subpar; nonetheless, contrasts can be perceived more vividly in this light. This is the rationale behind the use of these lamps in environments where it is crucial to recognise objects and contours for safety, such as on highway bridges, tunnels, junctions, and so forth. At 260°C, conventional discharge tubes can achieve the low-pressure sodium discharge's ideal pressure of approximately 0.4 Pa. This temperature is often reached and maintained using an exterior bulb.

High-Pressure Mercury Vapour Lamps: Increased mercury vapour pressure results in radiation with more spectral lines, some of which are in the visible spectrum (405, 436, 546, and 577/579 nm). The luminous efficacy rises as a result, reaching values of 40–60 lm–W1 at pressures of 105–107 Pa (1–100 at). Unsaturated mercury vapour is used in these lamps' operation, which means that all of the mercury in the discharge tube has evaporated while maintaining a consistent amount of mercury atoms per unit volume. Therefore, compared to the majority of other discharge lamps, this type of lamp's functioning is more temperature independent. The lack of spectral lines in the long wavelengths (reds) of the spectrum, which results in low CRI, is one disadvantage of these lamps. By introducing metal halide compounds into the discharge tube in order to produce radiation across the entire visible spectrum, it is possible to improve colour rendition. These lights are called Metal halide lamps.

High-Pressure Sodium Lamps: This light source is particularly well-liked because of its excellent luminous efficacy and long lifespan. When compared to low-pressure sodium lights, the spectrum is greatly expanded due to the rise in sodium vapour pressure, and colour rendition is also improved. The luminous efficacy is also reduced as a result, but it is still higher than that of other high-intensity discharge lamps. Some of these lamps also contain mercury, usually in the form of sodium amalgam, to strengthen the discharge field and reduce discharge current. Lower lamp current and higher lamp voltage enable the ballast to be smaller and less expensive. However, the lamp's lifespan is significantly shortened by the addition of sodium amalgam.

Electromagnetic Ballasts: By restricting the discharge current, electromagnetic ballasts are frequently employed to stabilise the lamp at the necessary operating point. According to Figure. 2, the intersection of the lamp and ballast characteristics determines the lamp's operating point. The feature known as the ballast line, which may be observed during the lamp's warm-up period, depicts the variation of lamp power vs lamp voltage for a constant line voltage. The feature known as the lamp line, which can be determined by changing the line voltage, is what determines how the lamp power varies as a function of the lamp voltage for various line voltages. With changes in lamp wattage, some lamps, like high-pressure sodium, show a significant shift in lamp voltage. For the sake of ballast design, trapezoids have been constructed that specify the maximum and minimum permitted lamp wattage vs lamp voltage, as shown in Fig. 2.

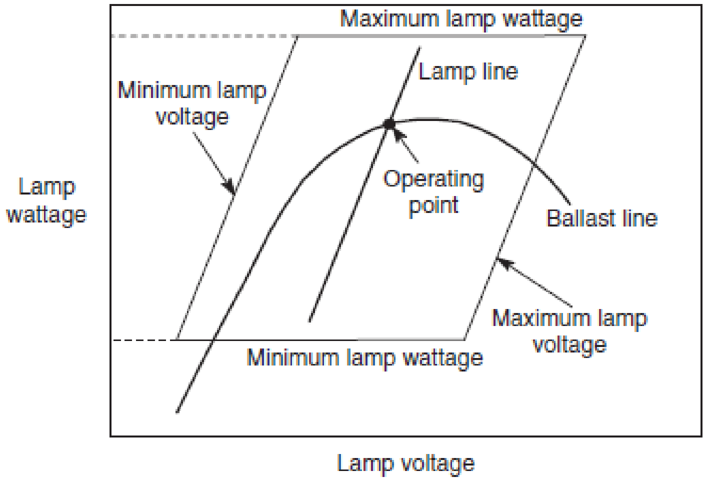

Figure 2: Lamp and Ballast Characteristics.

Basic electromagnetic ballast is shown in Figure 3 and is used to power low- and high-pressure bulbs at line frequencies (50–60 Hz). The usual circuit for supplying fluorescent lamps with preheating electrodes is shown in Figure 3(a). This circuit essentially uses a series inductor tolimit the current through the discharge. The short circuit current travels across the circuit when the glow switch is first closed, heating the electrodes.

1. Lamp wattage
2. lighting voltage
3. greatest lamp wattage
4. Lowest lamp wattage
5. light line
6. weigh line
7. maximum voltage for lamps
8. Lowest light voltage
9. Operating point

After the glow switch opens a split second later, the energy in the ballast inductor induces an 800V voltage spike between the lamp electrodes, which ultimately results in the discharge breakdown. Once lit, the voltage of the lamp is lower than the line voltage, and the glow switch is left open during the course of regular lamp operation. Glow switches typically consist of two bimetal strips enclosed in a tiny tube that is filled with an inert gas. When igniting a lamp, a 10 nF external capacitor is employed to improve glow-switch performance and lessen radio interference. Finally, a capacitor placed across the line input is necessary in these sort of inductive ballasts in order to reach a respectable value for the input power factor.

High-pressure discharge lamps' starting voltages can range from 2500 V for a lamp at room temperature to 30-40 kV to reignite a hot bulb, and they are often greater than low-pressure discharge lamps. Therefore, these bulbs no longer work with the basic ignition system based on the glow switch. Two typical configurations for supplying high-intensity discharge lights are shown in Figures 3(b) and (c). While autotransformers are utilised to achieve greater voltage spikes for lamp ignition, a series inductor is also employed to limit the lamp current during steady-state operation. The inductor ballast can be utilised as an ignition transformer for greater line voltages and close proximity between the starter and lamp, as shown in Fig. 3(b). Other times, a separate igniting transformer is required to deliver stronger voltage spikes and prevent the impact of connection cables' parasitic capacitance (Figure 3 c).

Only installations with low voltage fluctuations are advised to use the inductive ballast because it regulates low lamp output against line voltage variation.

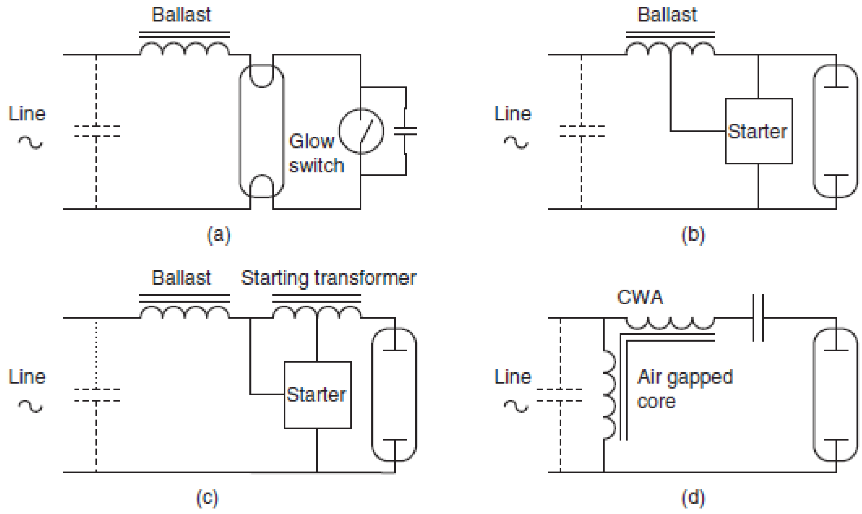

Figure 3: Typical electromagnetic ballast used to supply discharge lamps at low frequency.

The circuit in Fig. 3(d) is typically utilised when reliable lamp power regulation is required. The capacitor is connected in series with the bulb in this circuit, which is also known as a constant wattage autotransformer (CWA) to control the discharge current. The CWA also has a higher input power factor, a lower line extinguishing voltage, and lower line beginning currents than a typical inductive ballast. Electromagnetic ballasts' key benefit is simplicity, which also results in low cost and great reliability. They do, however, have a large size and weight due to the fact that they work at line frequencies, which are commonly 50 to 60 Hz. The following list includes several significant problems of electromagnetic ballasts [9]–[11].

a) Low efficiency, particularly for ballasts that regulate lamp power well against variations in line voltage.
b) Poor ignition and restart reliability. The lamp's ignition may not work properly if the voltage spike is not appropriately placed inside the line period.
c) The lamp's luminous flux is challenging to dim.
d) As lamps age, their operating point shifts, shortening their lifespan.
e) A high level of harmonic distortion and a low input power factor.
f) To improve power factor, large capacitors are required across the line input.
g) The possibility of overcurrent due to ballast saturation brought on by some discharge lamps' rectifying effects, particularly near the end of their useful lives.
h) Stroboscopic and flickering effects brought on a low frequency supply. The lamp's output energy is dependent on its immediate input power. Flicker is the term for the instantaneous change in light output that happens when power is delivered from an ac line. The resulting light frequency is 120 Hz for a line frequency of 60 Hz.
i) When swiftly moving objects are observed under these lamps, they appear to move slowly or even stop completely, despite the fact that this fluctuation is too fast for the human eye to perceive. This phenomenon, known as the stroboscopic effect, can be extremely hazardous in industrial settings. A flicker index is a number between 0 and 1. The likelihood of a perceptible stroboscopic effect increases with the flicker index.
j) Not appropriate for dc applications (emergency lighting, auto lighting, etc.).

CONCLUSION

In comparison to conventional electromagnetic ballasts, electronic ballasts have a number of advantages, such as greater efficiency, a longer bulb life, less flicker, and better colour rendering. They work by converting the incoming AC voltage to DC voltage, which is used to control the lamp current, and then converting it back to high-frequency AC voltage. Electronic ballasts come in two primary categories: passive and active. While active ballasts employ a power factor correction circuit to increase energy efficiency, passive ballasts use a resonant circuit to control the current. Due to their high energy efficiency and low maintenance requirements, electronic ballasts are frequently utilised in domestic, commercial, and industrial settings. Overall, controlling the electrical current that passes through fluorescent bulbs with electronic ballasts is a financially sensible and environmentally responsible approach.

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CHAPTER 16

A BRIEF DISCUSSION ON POWER SUPPLIES

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ABSTRACT:

In order to perform properly, electrical and electronic gadgets require a constant and dependable supply of power, which is provided by power supplies. They are available in a variety of forms and styles, such as linear, switch-mode, and battery-powered power supply. The requirements of the application, such as the output voltage and current, efficiency, size, and cost, determine the type of power supply that should be used. An overview of power supply, including kinds, uses, and applications, is given in this chapter.

KEYWORDS:

Linear Series Voltage, Linear Shunt Voltage, Power Supplies, Series Voltage Regulator, Shunt Voltage Regulator.

INTRODUCTION

Most electrical equipment needs power supplies. Their uses span a wide range of product categories, from consumer electronics to industrial utilities, mill watts to megawatts, handheld devices to satellite communications. A power supply is by definition a device that transforms the output of an ac power line into a constant dc output or numerous outputs. A smooth voltage is created by filtering the ac voltage after it has first been rectified to create a pulsing dc. Last but not least, the voltage is controlled to maintain a consistent output level regardless of changes in the ac line voltage or circuit loads. The rectification, filtering, and regulation processes of a dc power supply are shown in Figure 1. Other chapters cover the transformer, rectifier, and filtering circuits. We will focus on the functionality and properties of the regulator stage of a dc power supply in this chapter [1], [2].

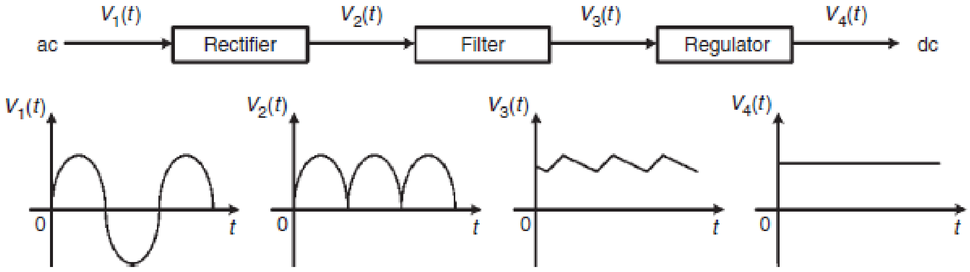

Figure1: Block diagram of a dc power supply.

A dc power supply's regulator stage typically consists of a control circuit to operate a pass element (a solid-state device such a transistor, MOSFET, etc.), a feedback circuit, and a steady reference voltage. The regulation is carried out by detecting fluctuations at the dc power supply's output. To drive the pass element and eliminate any variations, a control signal is generated. The dc power supply's output is virtually kept constant as a result. The pass element in a transistor regulator is a transistor, which can be used to control the output voltage either in its active area or as a switch.

The regulator is referred to as a linear voltage regulator when the transistor functions at any location within its active region. The circuit is referred to as a switching regulator when the transistor only functions at cutoff and at saturation.

Series or shunt forms of linear voltage regulators are additional categories for these devices. The pass transistor is linked in series with the load in a series regulator, as shown in Figure 2. The pass transistor's conduction is regulated by sensing a portion of the output voltage through the voltage divider network R1 and R2, comparing that voltage to the reference voltage VREF, and using the resulting error signal to do so. In this manner, the output voltage given to the load circuit is virtually maintained constant while the voltage drop across the pass transistor is changed.

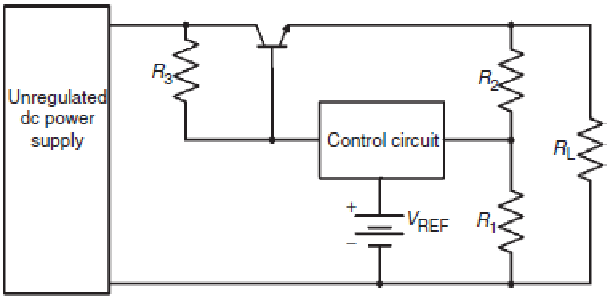

Figure 2: linear series voltage regulator

In the shunt regulator depicted in Figure 3, the load is connected in series with a voltage-dropping resistor R3, and the pass transistor is connected in parallel with the load. Regulation is accomplished by regulating the pass transistor's current conduction so that the current through R3 remains virtually constant. In this manner, the voltage across the load is maintained while the current through the pass transistor is changed. Switching voltage regulators, as opposed to linear voltage regulators, convert power using solid-state devices that may be switched between two states: fully on or fully off.

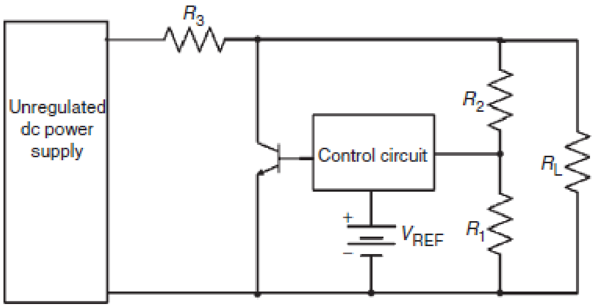

Figure 3: linear shunt voltage regulator.

Switching voltage regulators experience a significantly lower power loss than linear voltage regulators because the switching devices are not required to operate in their active zones. Pulse width modulator, Figure 4 illustrates a simplified version of a switching regulator. The high-frequency switch changes the unregulated dc voltage at an adjustable duty cycle from one level to another level. The feedback control, which makes use of a pulse-width-modulator (PWM) controller, regulates the output of the DC supply by adjusting the duty cycle of the switch using the control voltage. The identical task of turning an uncontrolled input into a regulated output can be accomplished by both switching and linear regulators. However, the characteristics and abilities of these two categories of regulators differ greatly.

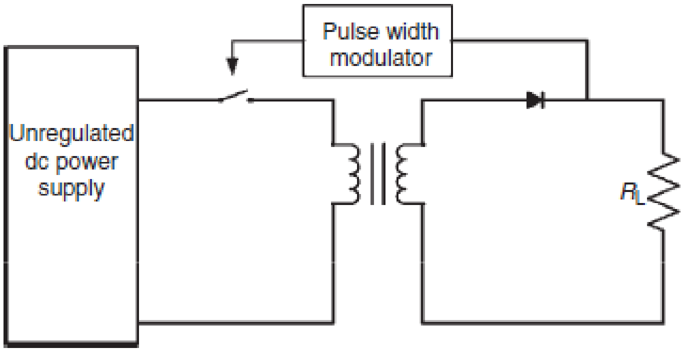

Figure 4: A simplified form of a switching regulator

The cost and performance of the regulator itself play a considerable role in the decision to use a certain type of regulator when developing power supply. Understanding the application's needs and choosing the regulator type that best satisfies them are prerequisites for using the more suitable regulator type in the design. Following are the benefits and drawbacks of linear regulators in comparison to switching regulators:

1. Switching regulators typically have an efficiency of 70 to 95 percent compared to linear regulators' 20 to 60 percent.
2. Switching regulators can be utilised in both step-up and step-down operations, whereas linear regulators can only be employed as a step-down regulator. 3. To operate off-the-line, linear regulators need a mains-frequency transformer. They are therefore large and heavy. On the other hand, switching regulators can be compact since they use high-frequency transformers.
3. Switching regulators may produce a significant amount of noise if they are improperly built, whereas linear regulators produce little to no electrical noise at their outputs.
4. Switching regulators are better suited for applications requiring high amounts of power, whilst linear regulators are better suited for applications requiring less than 20W.

DISCUSSION

Power supplies are essential parts of electrical and electronic devices because they provide a consistent and dependable supply of power for their effective operation. The majority of the gadgets we use on a daily basis, including cell phones, laptops, televisions, and even medical equipment, wouldn't function without power supplies. There are many different types and designs of power supply, each having special qualities and uses.

Different Power Supply Types: Power supplies come in a variety of forms, including battery-based, switch-mode, and linear power supplies. The most basic kind of power supply is a linear one, which consists of a transformer, a rectifier, and a voltage regulator. They reduce the mains' high voltage AC power to a lower voltage DC output. Although they are dependable and reasonably priced, linear power sources are less effective than other kinds.

Contrarily, switch-mode power supplies are more intricate but more effective than linear power supplies. To change the AC input voltage into a DC output voltage, they employ high-frequency switching techniques. Switch-mode power supplies are used frequently in applications that call for great efficiency and little power dissipation because they are more efficient than linear power supply. Particularly in portable applications like laptops, cell phones, and tablets, battery-based power supply are growing in popularity. They generate a DC output voltage using rechargeable batteries, which makes them very portable. Battery-based power supply, however, are inappropriate for applications that demand continuous operation because of their low capacity and frequent recharging [3]–[5].

Power supply purposes: Power supplies' main purpose is to offer a steady and dependable source of power so that electronic gadgets can operate as intended. Power supply must efficiently and noiselessly convert the AC input voltage to the necessary DC output voltage. Even under shifting load conditions and input voltage changes, the output voltage must maintain stability. Protection from overvoltage, overcurrent, and short circuits is a vital feature of power supply. Electronic devices are sensitive to changes in voltage and current, and they can be harmed if they are subjected to too much of either. Therefore, protective circuits must be included in power supplies to stop such events.

Applications of Power Supplies: Applications for power supply include everything from consumer gadgets to industrial and medical machinery. They are utilised in consumer devices including as routers, modems, smartphones, laptops, and televisions. Power supplies are utilised in control systems, robotics, motor drives, and instrumentation in industrial applications. In order to function properly, medical devices like MRI scanners, patient monitoring, and ultrasound machines need power sources.

Linear series voltage regulator: A voltage regulator known as a linear series voltage regulator controls the output voltage using a linear control element. It is an easy-to-use, dependable device that consistently outputs a DC voltage regardless of changes in the input voltage and load current. Power supply, instrumentation, and control systems are just a few examples of the many electronic applications that utilise linear series voltage regulators. A linear series voltage regulator functions by keeping the voltage drop across a series pass element constant. In order to create a DC voltage, the input voltage must first be converted to a lower AC value, rectified, and then filtered. The input of the linear voltage regulator is subsequently supplied with this DC voltage. A series pass element, a voltage reference, and a feedback circuit make up the linear voltage regulator. Usually, a power transistor or a Darlington pair serves as the series pass element, acting as a variable resistance to keep the voltage drop across it constant. The voltage reference is a precise voltage source that gives the feedback circuit a constant reference voltage. The feedback circuit changes the resistance of the series pass element to keep the output voltage constant by comparing the output voltage to the reference voltage. Despite changes in the input voltage or load current, this feedback loop makes sure that the output voltage stays constant.

Benefits: Compared to other types of voltage regulators, linear series voltage regulators provide a number of advantages. They are appropriate for low-power applications because they are straightforward, dependable, and affordable. They are particularly excellent for applications requiring high precision since they deliver an output voltage that is very stable and has no ripple and noise. The quick response time of linear series voltage regulators is another benefit. They are appropriate for applications that need for quick response times because they can react quickly to changes in the load current and maintain a constant output voltage. However, linear series voltage regulators have certain drawbacks as well. Due to the fact that they release surplus power as heat, they are less effective than other varieties of voltage regulators, such as switch-mode regulators. As the input voltage rises, the efficiency of linear series voltage regulators declines, increasing power loss and heat generation. Additionally, because of their narrow voltage range and unsuitability for applications requiring high voltage regulation, linear series voltage regulators cannot be used. They may need additional filtering to lower noise levels because they are also noise-sensitive.

Applications: Power supplies, instrumentation, and control systems are just a few of the many electronic applications that linear series voltage regulators are utilised in. Due to their low power dissipation and straightforward construction, they are frequently employed in low-power applications like battery-powered gadgets. Due to its high output voltage stability and minimal ripple and noise, linear series voltage regulators are also employed in precision applications like sensor signal conditioning and analog-to-digital converters.

Summary: Despite changes in the input voltage or load current, linear series voltage regulators are straightforward and dependable devices that produce a consistent output voltage. In numerous electronic applications, such as power supplies, instrumentation, and control systems, they are widely employed. Even though they have significant drawbacks including poorer efficiency and a smaller voltage range, they are nonetheless a vital part of many low-power and precise applications.

Linear shunt voltage regulator:A voltage regulator known as a linear shunt voltage regulator controls the output voltage using a shunt element. It is a straightforward and efficient device that consistently outputs DC voltage despite variations in input voltage and load current. In many electronic applications, including power supplies, measurement, and control systems, linear shunt voltage regulators are employed. A linear shunt voltage regulator functions by keeping the voltage drop across a shunt element constant. In order to create a DC voltage, the input voltage must first be converted to a lower AC value, rectified, and then filtered. The input of the linear voltage regulator is subsequently supplied with this DC voltage. Shunt element, voltage reference, and feedback circuit make up the linear voltage regulator. A Zener diode or transistor serves as the shunt element's typical variable resistance, maintaining a constant voltage drop across it. The voltage reference is a precise voltage source that gives the feedback circuit a constant reference voltage. The feedback circuit changes the resistance of the shunt element to maintain a consistent output voltage by comparing the output voltage to the reference voltage. Despite changes in the input voltage or load current, this feedback loop makes sure that the output voltage stays constant.

Benefits: Compared to other types of voltage regulators, linear shunt voltage regulators provide a number of advantages. They are appropriate for low-power applications because they are straightforward, dependable, and affordable. They are particularly excellent for applications requiring high precision since they deliver an output voltage that is very stable and has no ripple and noise. The quick response time of linear shunt voltage regulators is another benefit. They are appropriate for applications that need for quick response times because they can react quickly to changes in the load current and maintain a constant output voltage. Limitations apply to linear shunt voltage regulators as well, though. Due to the fact that they release surplus power as heat, they are less effective than other varieties of voltage regulators, such as switch-mode regulators. As the input voltage rises, the efficiency of linear shunt voltage regulators declines, increasing power loss and heat generation. Furthermore, linear shunt voltage regulators are unsuitable for applications requiring high voltage regulation due to their narrow voltage range. They may need additional filtering to lower noise levels because they are also noise-sensitive.

Applications: Linear shunt voltage regulators are frequently used in power supplies, instrumentation, and control systems, among other electronic applications. Due to their low power dissipation and straightforward construction, they are frequently employed in low-power applications like battery-powered gadgets. Due to its high output voltage stability and minimal ripple and noise, linear shunt voltage regulators are also employed in precision applications like sensor signal conditioning and analog-to-digital converters [6]–[8].

Summary: Despite changes in the input voltage or load current, linear shunt voltage regulators maintain a consistent output voltage. They are inexpensive, simple, and efficient. In numerous electronic applications, such as power supplies, instrumentation, and control systems, they are widely employed. Even though they have significant drawbacks including poorer efficiency and a smaller voltage range, they are nonetheless a vital part of many low-power and precise applications.

Integrated circuit voltage regulator:A voltage regulator type that uses an integrated circuit is known as an integrated circuit (IC) voltage regulator. Regardless of changes in the input voltage or load current, it is a very efficient and dependable device that offers a consistent DC output voltage. In a wide range of electronic applications, including power supplies, consumer electronics, and automotive systems, IC voltage regulators are frequently employed. The input and output terminals of an IC voltage regulator maintain a constant voltage differential in order to function. A DC voltage is created by rectifying and filtering the input voltage before applying it to the voltage regulator's input. A power transistor, an error amplifier, and a voltage reference are all components of the voltage regulator. The error amplifier compares the output voltage with the reference voltage to produce an error signal, and the voltage reference gives it a steady reference value to work with. The output voltage is then modified by the power transistor by altering the current that passes through it. Regardless of changes in the input voltage or load current, this feedback loop makes sure that the output voltage stays constant.

Advantages: Compared to other types of voltage regulators, IC voltage regulators provide a number of benefits. They are very effective because they control the output voltage through a switching mechanism. IC voltage regulators are excellent for applications that call for great efficiency and less heat generation since this switching method reduces power dissipation. The excellent accuracy and stability of IC voltage regulators is another benefit. They are perfect for applications requiring high precision because they produce an output voltage that is extremely stable and has no ripple and noise. Furthermore, IC voltage regulators are very durable and have a long lifespan. To assure their effectiveness and endurance, they are produced utilising premium materials and put through a rigorous testing process. Limitations exist with IC voltage regulators as well, though. Due to the intricacy of their design and production, they may be more expensive than other voltage regulator types, such as linear regulators. Additionally, due to their switching nature, IC voltage regulators could produce electromagnetic interference (EMI). Other nearby electronic equipment may be impacted by this EMI, necessitating extra shielding or filtering.

Applications: Power supply, consumer electronics, and automotive systems are just a few of the many electronic systems that require IC voltage regulators. Due to their low power dissipation and switching mechanism, they are frequently employed in applications that need great efficiency, such as battery-powered devices. Applications that need high accuracy and stability, like audio equipment, instrumentation, and communication systems, also use IC voltage regulators.

In summary, IC voltage regulators are incredibly efficient and dependable components that consistently deliver a constant output voltage despite changes in the input voltage or load current. In a wide range of electronic applications, such as power supply, consumer electronics, and automotive systems, they are frequently employed. Although they might cost more than other kinds of voltage regulators and produce EMI, they are nonetheless a crucial part of many high-efficiency and high-precision applications.

Switching regulators: A voltage regulator known as a switching regulator controls the output voltage using a switching mechanism. They are ideal for applications that need for great efficiency and less heat dissipation because they minimise power dissipation and heat generation. In many different electrical applications, including power supply, battery chargers, and LED drivers, switching regulators are utilised. A switching mechanism is used by a switching regulator to transform the input voltage into a controlled DC output voltage. A power switch, an inductor, a diode, and a capacitor are all components of the switching mechanism. The high frequency on/off operation of the power switch causes the inductor to store and release energy. The capacitor filters the output voltage while the diode ensures that the current only flows in one direction. By adjusting the power switches on and off times, the output voltage is adjusted. A feedback loop that compares the output voltage to a reference voltage and modifies the duty cycle as necessary controls the power switch's duty cycle.

Benefits: Switching regulators have a number of benefits over other voltage regulator designs. They are very effective because they control the output voltage through a switching mechanism. Switching regulators are excellent for applications that call for high efficiency and little heat generation because of this mechanism, which reduces power dissipation and heat creation. Switching regulators are excellent for applications that require voltage regulation over a wide range of input voltages since they also have a wide input voltage range. They are ideal for portable and battery-powered devices due to their extreme compactness and light weight. Limitations exist with switching regulators as well, though. Due to the complexity of their design and control circuitry, they may be more complicated than other forms of voltage regulators, such as linear regulators. Additionally, because of their switching process, they might produce electromagnetic interference (EMI), which could harm nearby electronic equipment.

Applications: Power supplies, battery chargers, and LED drivers are just a few of the numerous electrical devices that switch regulators are employed in. They are frequently used in systems for cars, solar-powered gadgets, and portable electronics that need great efficiency. Applications that need a large input voltage range, like industrial machinery, telecommunications, and medical devices, also use switching regulators.

In summary, switching regulators are extremely effective voltage regulators that control output voltage by a switching mechanism. They are extensively utilised in many different electrical applications, including LED drivers, battery chargers, and power supply. Many high-efficiency and wide-input voltage range applications require them, despite the fact that they may be more complex than other types of voltage regulators and that they may produce EMI [9]–[11].

CONCLUSION

Modern electronics are dependent on power supply to provide the energy required for devices to operate properly. The exact needs of the application, such as voltage and current output, efficiency, size, and cost, determine the best power supply to use. Switch-mode power supplies are more complex but more efficient than linear power supplies, which are simpler but less effective. The portability of battery-based power supply comes with the drawback of having a small capacity. In order to choose the appropriate power supply for a particular application, it is essential to understand the many types of power supplies and their properties.

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CHAPTER 17

UNINTERRUPTIBLE POWER SUPPLIES

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ABSTRACT:

Uninterruptible Power Supplies (UPS) are made to offer backup power in the event of power outages or voltage swings. To guarantee the ongoing operation of crucial equipment, UPS systems are widely employed in many different industries, including healthcare, telecommunications, and banking. We will examine the main characteristics and advantages of UPS systems in this article, as well as the various types of UPS technologies that are offered on the market.

KEYWORDS:

Line Interactive UPS, Power supply, Online UPS, Standby UPS, UPS system, Universal UPS.

INTRODUCTION

Uninterruptible Power Supplies (UPS) are made to offer backup power in the event of power outages or voltage swings. These systems are frequently employed across a number of industries to maintain the continuous operation of crucial machinery. In essence, a UPS system is a battery backup that, in the event of a power outage or other power issue, supplies electricity to the connected devices. We will examine the main characteristics and advantages of UPS systems in this article, as well as the various types of UPS technologies that are offered on the market. A UPS system's battery backup, surge protection, and voltage regulation are its main components. In the event of a power loss, the battery backup makes sure that the linked equipment is kept powered. The equipment is shielded from power surges brought on by lightning strikes or other power fluctuations thanks to surge protection. For sensitive machinery like computers, servers, and medical devices, voltage regulation helps to maintain a constant voltage level.

On sensitive loads in the electrical systems, power distortions such power interruptions, voltage sags and swells, voltage spikes, and voltage harmonics can have a detrimental effect. These delicate loads are given uninterrupted, dependable, and high-quality power using uninterruptible power supply (UPS) systems. Medical facilities, life support systems, data storage and computer systems, emergency equipment, telecommunications, industrial processing, and online management systems are among the applications of UPS systems. Particularly necessary in locations with frequent power fluctuations and outages are UPS systems. When there is a power loss, a UPS offers a backup power circuitry to supply critical systems. A UPS delivers consistent power to keep the crucial loads functioning in cases of brief power fluctuations or disturbed voltage. A UPS supplies backup power during prolonged power outages to keep the systems functioning long enough for them to be gracefully shut down. The majority of UPS systems also reduce harmonic and line disturbances. In general, a perfect UPS should be able to give uninterruptible power while also offering the required power conditioning for the specific power application [1]–[3].

As a result, the perfect UPS should have the following characteristics: regulated sinusoidal output voltage with low total harmonic distortion (THD) independent from changes in the input voltage or in the load, on-line operation, which means there should be no delay when switching from normal to backup mode, low THD sinusoidal input current, and unity power factor, high reliability, high efficiency, low EMI and acoustic noise, electric isolation, low maintenance, low cost, and water resistance.

It is obvious that no single setup can offer all of these advantages. Different UPS system configurations place more emphasis on some of the previously stated aspects. Figure 1 illustrates a typical UPS system given below-

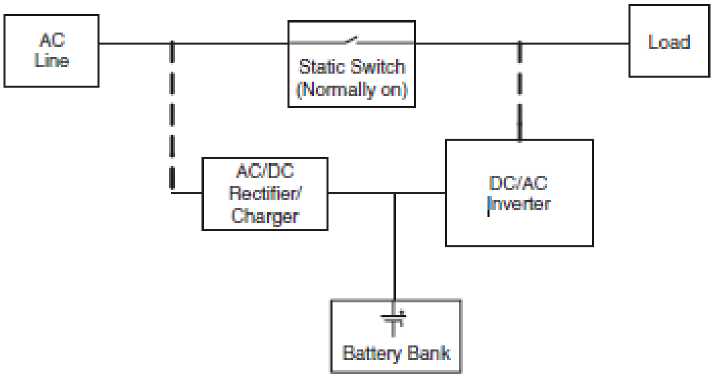

Figure1: Configuration of a typical standby UPS system.

Advantages of UPS Systems: Businesses and organisations can profit from UPS systems in a number of ways. A UPS system's primary advantage is that it guarantees the continuous operation of crucial equipment, which is crucial for companies that depend on technology to run their operations. UPS systems also guard against voltage fluctuations and power surges, which can seriously harm delicate equipment. Additionally, by supplying a steady power supply, UPS systems can increase the equipment's lifespan.

Different UPS technology types:

a) The industry offers a variety of UPS technologies, such as standby, line-interactive, and online double-conversion. Different types of UPS systems provide differing degrees of efficiency and protection.
b) The most basic form of UPS technology is the standby UPS. When the main power supply is cut off, it switches to battery power. The least amount of protection is offered by standby UPS systems, which are often less expensive than other types of UPS systems.
c) A more sophisticated sort of UPS technology that offers better protection against power fluctuations is the line-interactive UPS. The line-interactive UPS regulates voltage via a transformer and offers battery backup in the event of a power outage.
d) Online Double-Conversion UPS: The most cutting-edge UPS technology is the online double-conversion UPS. It offers the best level of defence against voltage changes, power surges, and power outages. A stable and reliable power supply is ensured by the online double-conversion UPS by converting AC power to DC power and then back to AC power.

DISCUSSION

Classification of UPS:

Standby UPS: Uninterruptible Power Supply (UPS) systems, such as standby UPS, are frequently used in households, small businesses, and computers. Because the linked equipment is powered directly by AC mains power and the UPS only switches to battery power when the mains power fails, this type of UPS is also referred to as an offline UPS. The main characteristics, advantages, drawbacks, and ideal applications of standby UPS will all be covered in this article [4].

Key Characteristics of Standby UPS: A standby UPS's main characteristics are voltage management, surge protection, and battery backup. In the event of a power loss, the battery backup makes sure that the linked equipment is kept powered. The equipment is shielded from power surges brought on by lightning strikes or other power fluctuations thanks to surge protection. For sensitive machinery like computers, servers, and medical devices, voltage regulation helps to maintain a constant voltage level.

Advantages of a standby UPS: Standby UPS has a number of advantages, including affordability, use, and dependability. The standby UPS is a common option for small enterprises and private use because it is reasonably priced when compared to other kinds of UPS systems. Additionally, it doesn't need any special wiring and is simple to install and use. For brief power outages, the standby UPS offers dependable backup power, shielding the connected devices from harm and data loss.

The drawbacks of standby UPS: Before selecting this kind of UPS system, standby UPS's restrictions must be taken into account. Only a little amount of backup power, typically between 5 and 15 minutes, is offered by the standby UPS. This is appropriate for brief power outages, but not for prolonged ones. There may be a small power outage while switching to battery power because it doesn't happen instantly. The connected equipment may nevertheless sustain damage despite the standby UPS's limited protection against power spikes and voltage fluctuations.The best applications for standby UPS: Small enterprises, residences, and personal PCs that need simple backup power protection should use standby UPS. It is also appropriate for non-critical equipment that can withstand a temporary power outage. For equipment like medical devices or data centres that needs a constant power supply, a standby UPS is not appropriate.

In summary, an economical and dependable Uninterruptible Power Supply (UPS) system is a standby UPS, which offers backup power protection during brief power outages. It is a popular option for small enterprises and personal use because it is simple to use and install. It does, however, have significant drawbacks, such as limited backup power, a temporary gap in power delivery, and insufficient protection against voltage fluctuations and power surges. The greatest candidates for standby UPS are non-critical devices that can withstand a brief power outage. It is not appropriate for sensitive applications or equipment that needs constant power supply.

On-line UPS: Online UPS is a sort of Uninterruptible electricity Supply (UPS) system that offers connected devices consistent, high-quality electricity. Because the incoming AC power is first converted to DC power, which is subsequently utilised to charge the battery and power the attached equipment, this type of UPS is often referred to as a double-conversion UPS. In this post, we'll examine the main traits and advantages of online UPS, as well as its drawbacks and ideal applications. The Schematic diagram of online UPS is given in Figure 2.

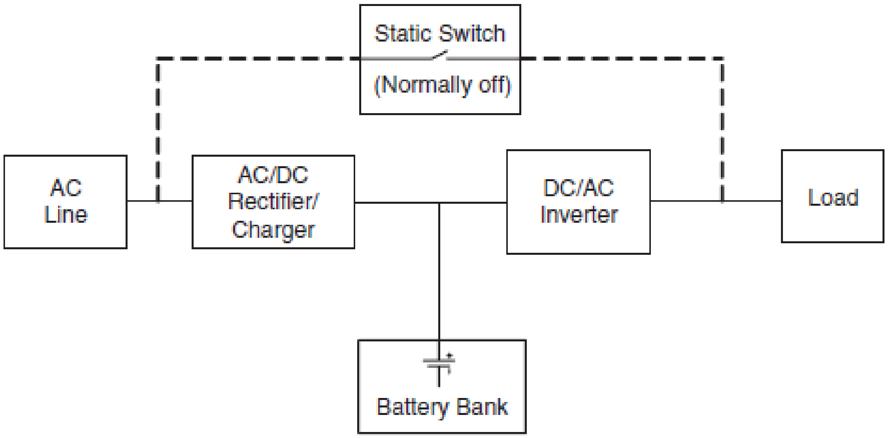

Figure 2: Schematic diagram of Online UPS.

Key Characteristics of Online UPS: An online UPS's primary characteristics include isolated output, double conversion, and high power efficiency. The double-conversion technique makes sure that the incoming AC power is converted to DC power first, which is then used to recharge the battery and power the attached devices. The connected equipment receives a clean, reliable, and noise- and interference-free power supply from the isolated output. Due to the online UPS's excellent power efficiency, less energy is lost during conversion, which lowers energy expenses and lowers the environmental impact.

Advantages of Online UPS: Numerous advantages are provided by online UPS, including strong power quality, reliable power backup, and surge protection. The linked equipment is kept powered in the event of a power outage thanks to the continuous power supply provided by online UPS. The equipment is shielded against power surges brought on by lightning strikes or other power fluctuations thanks to the surge protection feature. For sensitive equipment like servers, medical devices, and laboratory equipment, a clean and consistent power supply is crucial, and the high power quality of online UPS provides this.

Online UPS's drawbacks: Before selecting this kind of UPS system, it is important to take into account the limits of online UPS. In comparison to other types of UPS systems, the double-conversion technique employed in online UPS results in greater expenses. Increased energy use and heat production from online UPS's continuous operation may call for additional cooling systems. The performance of some equipment may be impacted by the online UPS's potential to generate some level of noise and interference into the power supply.

Applications of Online UPS: The best uses for online UPS are important applications like data centres, hospitals, and laboratories that need a consistent, high-quality power supply. It is also appropriate for machinery like telecommunications equipment and industrial machinery that needs voltage management and surge protection. For non-critical applications that can handle a temporary power outage, an online UPS is not recommended because of the greater price and energy usage.

In summary, Critical applications can benefit from continuous power backup and surge protection provided by online UPS, a dependable and high-quality form of uninterruptible power supply (UPS) system. It makes use of double-conversion technology to guarantee a stable, clean, and noise- and interference-free power supply. However, it has several drawbacks, such as increased expenses, more energy usage, and higher heat generation. The best uses for online UPS are important applications like data centres, hospitals, and laboratories that need a consistent, high-quality power supply. It is not appropriate for non-critical applications that can endure a brief power outage.

Line-interactive UPS: An Uninterruptible Power Supply (UPS) system called a line-interactive UPS is made to offer connected equipment power backup and surge protection. Instead of relying on the battery backup, this kind of UPS system uses an automated voltage regulator (AVR) to regulate the incoming AC voltage and keep it within a safe range. In this post, we'll look at the main advantages and characteristics of line-interactive UPS, as well as some of its drawbacks and ideal applications.

Important Properties of Line Interactive UPS: Automatic voltage regulation, battery backup, and surge protection are among the essential characteristics of a line-interactive UPS. The AVR is used by the automatic voltage regulation feature to regulate the input AC voltage and maintain it within a safe range, protecting the connected equipment from power surges and voltage spikes. The connected equipment is kept powered in the event of a power outage thanks to the battery backup feature. The equipment is shielded against power surges brought on by lightning strikes or other power fluctuations thanks to the surge protection feature.

Line-interactive UPS advantages include: Voltage regulation, surge prevention, and dependable power backup are just a few advantages of line-interactive UPS. Automatic voltage control safeguards linked devices against damaging power surges and voltage spikes that could also result in data loss. In the event of a power outage, the battery backup feature makes sure that the connected equipment is kept powered, preventing downtime and data loss. The equipment's lifespan is increased by the surge protection mechanism, which shields it against power surges brought on by lightning strikes or other power irregularities.

Line-interactive UPS restrictions: Prior to selecting a line-interactive UPS system, one should be aware of its limitations. In situations when there are significant voltage fluctuations or brownouts, the automated voltage control mechanism could not work as intended, necessitating the use of the battery backup. There is a chance that the battery backup won't last long enough for some essential applications. The performance of some equipment may be impacted by the line-interactive UPS's potential to introduce some level of noise and interference into the power supply.

The best applications for line-interactive UPS: Small companies, home offices, and home entertainment systems are some of the applications that line-interactive UPS is most suited for. These applications also need reliable power backup and surge protection. It is also appropriate for devices like computers, servers, and networking hardware that need voltage regulation. Because the battery backup may only have a short runtime, line-interactive UPS is not appropriate for applications that need continuous power backup. Additionally, because the line-interactive UPS may generate some level of noise and interference, it is not appropriate for applications that need a clean and reliable power supply.

In summary, an effective and dependable Uninterruptible Power Supply (UPS) system that offers linked equipment power backup, voltage regulation, and surge protection is called a line-interactive UPS. It does not need to rely on the battery backup since an automated voltage regulator (AVR) adjusts the incoming AC voltage and keeps it within a safe range. It does, however, have several drawbacks, such as a short runtime, poor performance under extreme voltage changes, and noise/interference. Small companies, home offices, and home entertainment systems are some of the applications that line-interactive UPS is most suited for. These applications also need reliable power backup and surge protection. It is not appropriate for applications that need a clean, consistent power source or continuous power backup.

Universal UPS: An Uninterruptible Power Supply (UPS) system known as a "universal UPS" is made to work with a variety of input voltages, frequencies, and output loads. In areas with low power quality, where input voltage and frequency might vary dramatically, this kind of UPS is frequently utilised. The main characteristics, advantages, drawbacks, and ideal applications of Universal UPS will all be covered in this article. The schematic arrangement of Universal UPS illustrated in Figure 3.

Key Characteristics of a Universal UPS: Wide input voltage and frequency range, high efficiency, and adaptable output configuration are some of a Universal UPS's important characteristics. The wide input voltage and frequency range of the UPS enables it to function under a variety of input conditions, making it appropriate for usage in areas with poor power quality. The UPS's great efficiency aids in lowering energy usage and running expenses. The UPS may be set up to match the unique needs of the connected equipment thanks to its variable output configuration.

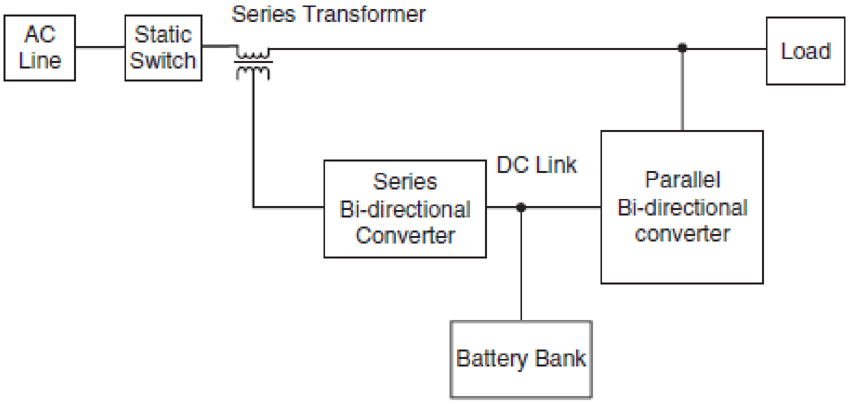

Figure 3: schematic arrangement of Universal UPS.

Advantages of a Universal UPS: High efficiency, dependable power backup, and compatibility with a broad range of input circumstances are just a few advantages that universal UPS offers. The UPS's excellent efficiency contributes to lower energy consumption and running expenses, which is crucial in areas with expensive or unstable electricity. In the event of a power outage, the dependable power backup feature makes sure that the connected equipment is kept powered, preventing downtime and data loss. The Universal UPS is appropriate for use in a number of applications, including data centres, industrial facilities, and distant locations due to its flexibility with a wide range of input circumstances.

The drawbacks of Universal UPS: Before selecting this kind of UPS system, it is important to take into account the restrictions of Universal UPS. Since other types of UPS systems may not offer the same level of voltage regulation due to the wide input voltage and frequency range, they might not be appropriate for applications requiring a high level of voltage stability. Because of its excellent output power efficiency, the UPS may not be appropriate for applications that call for great power density. Additionally, the Universal UPS could be more expensive and sophisticated than other types of UPS systems, making it unsuitable for small-scale applications.

Ideal Applications for Universal UPS: The applications that necessitate compatibility with a broad range of input circumstances, such as data centres, industrial facilities, and remote sites, are ideally suited for universal UPS. It is also appropriate for industries like telecommunications, healthcare, and financial services that demand high dependability and efficiency. Applications requiring a high level of voltage stability or high power density are not suited for Universal UPS. Additionally, it is not appropriate for small-scale applications that call for a straightforward and affordable UPS solution.

An effective and dependable Uninterruptible Power Supply (UPS) system, the universal UPS is made to work with a variety of input voltages, frequencies, and output loads. High efficiency, dependable power backup, and compatibility with a wide range of input conditions are just a few advantages it provides. It does, however, have significant drawbacks, such as lower voltage stability, lower output power, and greater complexity and expense. The applications that call for compatibility with a broad range of input conditions, high efficiency, and reliability such as data centres, industrial facilities, and remote locations are ideally suited for universal UPS. Applications requiring a high level of voltage stability or high power density are not appropriate for it.

Applications of UPS: There are several uses for UPS systems across numerous industries. Their typical uses range from low power ratings for desktop computers to medium power ratings for hospitals, life support systems, data storage, and emergency equipment to high power ratings for telecommunications, industrial processing, and online management systems. For these applications, certain factors need to be taken into account. The UPS (figure 4) should provide at least 90 minutes of backup for emergency lighting and systems. The UPS is intended to supply backup power to delicate loads for 15-20 minutes, excluding emergency systems. The system will then be gracefully shut down if the power is not restored by then. A bigger battery that costs more and takes up more space is needed if a longer backup period is taken into account. Some UPS systems are built to give process equipment and high power applications adequate time to start up secondary power sources like diesel generators.

It should be mentioned that UPS systems increase the electrical system's complexity for industrial applications. They also increase the price of installation and ongoing maintenance. They might also make the system more non-linear, reduce its effectiveness, and damage the input PFC mechanism. The power rating of the UPS should be properly chosen taking into account the current load and any potential extensions. In many applications, surges and spikes in the input voltage are more harmful than power outages. In place of a UPS, another device can be used with these systems. When choosing a UPS, load characteristics should also be taken into account. The inrush current, which can be 2.5 times the rated current for motor loads, should be taken into account.

The UPS with larger transient overloads is a good UPS for motor loads. The input current for non-linear loads, like switching power supplies, is not sinusoidal. The instantaneous current is therefore greater than the RMS current. When choosing a UPS, this large instantaneous current should be taken into account. To support sensitive loads in a power distribution network, two alternative strategies are used. Many different UPS units work in parallel to supply vital loads in a dispersed way, which is better suited for highly proliferating loads like medical equipment, data processing, and telecommunications. Flexible placement of UPS units creates a critical load network in the system. Figure 4 depicts a typical on-line distributed UPS system. The key benefits of distributed systems are their high degree of flexibility and redundancy. The addition of additional UPS systems can sustain an increase in individual load. It is also possible to put off thinking about potential extensions until the loads are added. However, there are significant drawbacks to this approach.

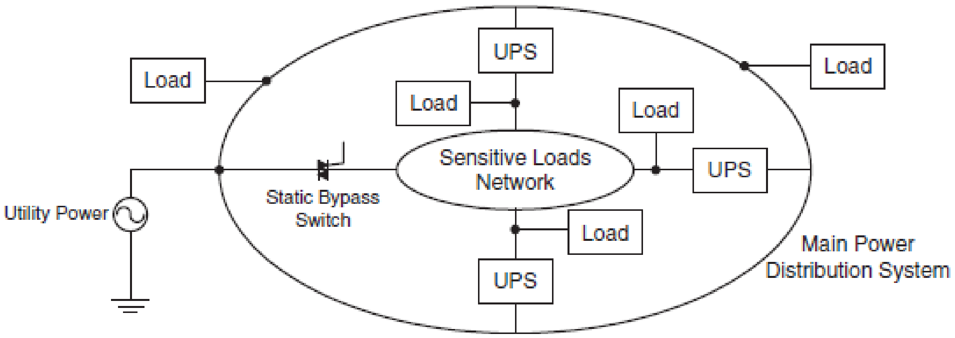

Figure 4: Typical configuration of a distributed UPS network.

It can be challenging to divide up the load among different UPS units. To achieve the best load sharing, complex digital control techniques and unit-to-unit communication are needed. The second drawback is that it is challenging and requires workers who have received specialised training to monitor the entire system. The other way to support scattered loads is to employ a sizable UPS unit to centrally supply all the critical loads. Applications in the industrial and utilities sectors might benefit more from this strategy. This approach has the benefit of being simpler to maintain and debug. On the other hand, the drawbacks include a lack of redundancy and hefty installation costs. Additionally, when choosing the initial UPS unit, consideration for system expansion should be made [5]–[8].

CONCLUSION

In summary, UPS systems are crucial for assuring the continuous operation of vital equipment in a variety of businesses. In the event of power outages or voltage fluctuations, which can seriously harm delicate equipment, they offer backup power. Choose the proper sort of UPS for your unique demands because the various UPS technologies on the market offer varied degrees of efficiency and protection. UPS systems have evolved into an essential component of contemporary infrastructure as a result of the increasing reliance on technology across many industries.

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CHAPTER 18

AUTOMOTIVE APPLICATIONS OF POWER ELECTRONICS

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ABSTRACT:

By enabling the creation of electric and hybrid vehicles, power electronics have revolutionised the automobile industry. Various vehicle applications, including the drivetrain, safety systems, and infotainment systems, employ power electronics components. An overview of power electronics applications in the automotive sector including those for electric and hybrid vehicles is given in this chapter. In addition, the article covers the difficulties in applying power electronics in the automotive industry as well as the future directions of power electronics research in this chapter.

KEYWORDS:

Electric Hydride Vehicles, Electromechanical Power Conversion, Power Electronic Component, Power Electronics Automotive.

INTRODUCTION

As environmental concerns and the need to cut greenhouse gas emissions have grown in recent years, the automobile industry has seen a substantial change in favour of electric and hybrid vehicles. Advances in power electronics technology have made the transition to electric and hybrid vehicles possible. Power electronics has improved the performance and dependability of electric and hybrid car components, enabling the creation of more economical and ecologically friendly automobiles. The use of electronic principles in the conversion and control of electric power is known as power electronics. The automotive industry has used power electronics technology in a number of applications, including entertainment, safety, and engine systems. Electric power is converted and controlled in electric and hybrid vehicle powertrains using power electronics components as power inverters, DC/DC converters, and motor controllers [1]–[3].

Electric motors, which power electric vehicles (EVs), are managed by motor controllers that draw electricity from batteries via power inverters. The power inverter transforms the battery's DC power into AC power, which is used to regulate the electric motor's speed and torque. In order to convert and regulate the flow of electricity between the battery and the internal combustion engine, hybrid vehicles (HVs) also employ power electronics components like DC/DC converters and motor generators. Additionally, airbag systems, electronic stability control, and anti-lock brake systems (ABS) all employ power electronics components. In order to prevent skidding, ABS systems use power electronics components to regulate the amount of braking force supplied to each wheel. While airbag systems employ power electronics to initiate airbag deployment following a collision, ESC systems use power electronics to detect and correct vehicle instability.

Modern automobile infotainment systems are growing more intricate and sophisticated, requiring more electronics power to provide services like connectivity, music, and navigation.

Infotainment systems use power electronics parts including audio amplifiers, power management units, and wireless charging devices to enhance the entire driving experience. Power electronics in the automotive industry provide many advantages, but there are still issues that need to be resolved. The high cost of power electronics components, which might raise the price of electric and hybrid vehicles, is one of the problems. Power electronics parts must be dependable, long-lasting, and economical for the car sector. Power electronics are difficult to integrate into safety and infotainment systems due to their high component costs, which can raise the cost of the car as a whole. The dependability of power electronics parts in demanding automotive settings, such as hot temperatures and vibrations, is another difficulty. For the vehicle to be safe and reliable, power electronics components must be able to resist these hostile environments. More durable power electronics components that can endure the challenging automobile settings are still being developed.

The evolution of the automobile industry has been significantly aided by power electronics, which has allowed for the creation of more environmentally friendly and efficient vehicles. Applications for power electronics components in the car sector include the powertrain, safety systems, and infotainment systems. Despite the difficulties in incorporating power electronics in the automobile sector, work is being done to provide more dependable, long-lasting, and affordable power electronics components. Power electronics technology developments will continue to be crucial for the car industry's future.

A significant number of electrical, electromechanical, and electronic loads that are essential to vehicle functioning, passenger safety, and comfort, make up the comprehensive electrical system found in modern automobiles. In order to condition the power produced by the alternator, process it suitably for the vehicle's electrical loads, and regulate the operation of these loads, power electronics is playing an increasingly significant role in automotive electrical systems. Power electronics is also a technology that makes a variety of future loads with new features and capabilities possible. These loads include electric propulsion, active suspension, controlled lighting, and electromagnetic engine valves [4], [5].

The Present Automotive Electrical Power System: Modern cars can have over 200 different electrical loads, each requiring an average of over 800W of power.

Headlights, taillights, cabin lamps, starters, fuel pumps, wipers, blower fans, fuel injectors, transmission shift solenoids, horns, cigar lighters, seat heaters, engine control units, cruise controls, radios, and spark ignition are just a few examples of these.

Modern internal combustion engine (ICE) cars use an electrical power system similar to the one in Figure 1 to power these loads. A Lundell (claw-pole) alternator, an engine-driven three-phase wound-field synchronous machine, produces power. An electronic regulator that manages the machine's field current rectifies the ac voltage and regulates the dc output to roughly 14V. A 12V lead-acid battery is charged while the loads are powered by the alternator. When the engine is not running or when the demand for electrical power is greater than the alternator's output power, the battery supplies the high power required by loads like the starter. The battery evens out the system voltage by functioning as a sizable capacitor.

Fuse-based circuits and point-to-point wiring are used to distribute power to the loads. The fuses, which are housed in one or more fuse boxes, guard the wires against fire and overheating in the event of a short. The majority of the loads are directly managed by mechanical switches that must be operated by hand. The dashboard, door panels, and ceiling are just a few places where the driver or passengers can easily access these major switches. The starter is one of the heavy loads that is indirectly switched using electromechanical relays.

System Environment: Automotive power electronic equipment is designed with the difficult electrical and climatic conditions present in the modern automobile in mind. Static and transient voltage ranges, electromagnetic interference and compatibility requirements (EMI/EMC), mechanical vibration and shock, temperature and other environmental conditions, and EMI/EMC requirements are some important elements influencing the design of electronics for this application. The aspects that have the greatest impact on the design of power electronics for automotive applications are briefly discussed in this section. The reader is referred to and the articles cited therein for more comprehensive guidelines on the design of electronics for automotive applications, from which most of the information presented here is derived. Automotive power electronic equipment is designed with the difficult electrical and climatic conditions present in the modern automobile in mind. Static and transient voltage ranges, electromagnetic interference and compatibility requirements (EMI/EMC), mechanical vibration and shock, temperature and other environmental conditions, and EMI/EMC requirements are some important elements influencing the design of electronics for this application. The aspects that have the greatest impact on the design of power electronics for automotive applications are briefly discussed in this section.

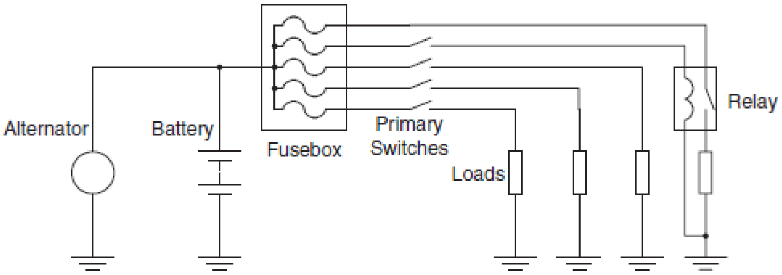

Figure 1: 12-V point-to-point automotive electrical power system.

Table 1: Static voltage range for the automotive electrical system.

Static voltage condition	**Voltage**
Nominal voltage with engine on	14.2V
Nominal voltage with engine off	12.6V
Maximum normal operating voltage	16V
Minimum normal operating voltage	9V
Minimum voltage during starting	4.5V
Jump start voltage	24V
Reverse battery voltage	−12V
Maximum voltage with alternator regulator failure followed by battery failure	130V

Static voltage ranges: The majority of modern autos use a lead-acid battery for energy storage and buffering along with a Lundell-type alternator to supply dc electrical power. The alternator controls the nominal battery voltage, which is 12.6 volts, to 14.2 volts when the engine is running in order to keep the battery at a high level of charge. In reality, the regulating voltage is changed to account for temperature and the properties of the battery. For instance a 14.5V regulation voltage at 25°C with a 10 mV/°C adjustment is stated. The bus voltage will be maintained between 11 and 16 volts under typical working circumstances. Equipment that is safety-critical is normally required to function even when the battery is discharged to 9V, and under certain circumstances, equipment that is beginning may experience a bus voltage as low as 4.5–6V.

When designing automobile electronics, a larger range of conditions are occasionally taken into account in addition to the standard operating voltage range. Reverse polarity battery installation is one scenario that could arise, with a bus voltage of roughly 12V as a result. Another instance of static overvoltage can happen while starting a vehicle with a jumper from a 24-V system, such as one on a tow truck. The failure of the alternator voltage regulator might lead to additional static overvoltage problems. This can lead to a bus voltage of up to 18V, battery electrolyte boiloff, and an uncontrolled bus voltage of up to 130V after that. Although it is typically impractical to design electronics for functioning under such severe fault circumstances, it is important to be aware that they can exist. The range of static voltages that can be anticipated in the vehicle electrical system is summarised in Table 1.

DISCUSSION

Functions Enabled by Power Electronics: Power electronics has been a key component in the development of new automotive features like the antilock braking system (ABS), traction control, and active suspension as well as the electrification of legacy features like the engine cooling fan over the past 20 years. Given that many new features being explored for inclusion in autos require power electronics, this trend is projected to continue. This section discusses some of the existing functions that have benefited from power electronics as well as some of the new functions that have been made possible by it.

High intensity discharge lamp: Fog and low-beam headlights on cars are starting to use high intensity discharge (HID) lamps. In comparison to conventional halogen lamps, HID lamps provide more luminous efficacy, greater dependability, longer life, and more styling options. An HID lamp has a life of around 2000 hours as opposed to a halogen lamps 300–700 hours, and its luminous efficacy is more than three times greater. As a result, HID lamps significantly increase road illumination while using the same amount of electricity, and in most situations, they should last the lifetime of the vehicle. Due to their closer colour spectrum to that of the sun than halogen lamps, HID lamps also generate whiter light. The filament in high intensity discharge lights is absent. Instead, light is produced by firing an arc through a pressurised combination of mercury, xenon, and vaporised metal halides; mercury creates the majority of the light, metal halides decide the colour spectrum, and xenon helps shorten the lamp's startup time. HID lamps need power electronic ballasts to function, as opposed to halogen lamps, which can be powered directly from the 12-V electrical system [6]–[8].

To ignite the arc between the electrodes, a high voltage pulse of 10 to 30 kV is initially required, and a voltage of roughly 85 V is required to maintain the arc. A simplified power electronic circuit for starting and operating a HID bulb is shown in Figure 2. The HID light 12 V Starter Boost converter is enhanced by a step-up dc-dc converter. An HID lamp ballast's simplified power electronic circuit converts voltage from 12 volts to the voltage required for the HID lamp to operate steadily. For this purpose, any dc-dc converter that has the ability to step increase the voltage, such as the boost or flyback converter, may be used. The ac voltage needed to drive the bulb steadily is then produced using an H-bridge. A circuit that delivers an inductive voltage kick, as shown in Figure 2, can serve as the arc-initiating circuit's most basic component.

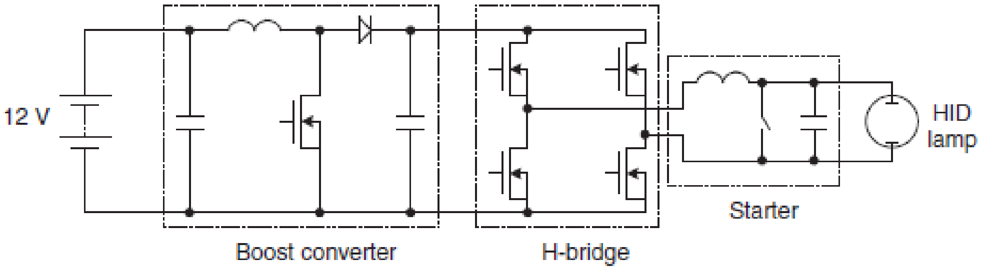

Figure 2: Simplified power electronic circuit for an HID lamp ballast.

Pulse-width Modulated Incandescent Lighting: The 14V electrical system used in today's cars may be replaced with a 42V electrical system in the future. HID lighting systems that operate off a 42V bus can be developed with ease since HID bulbs are operated through a power electronic ballast. HID lighting's high price, which can be up to a factor of 10 more than incandescent lighting, generally restricts its use to headlight applications. It is also possible to use incandescent lamps that are compatible with 42V systems. Lamp lifetime is significantly reduced, though, because a much longer, thinner filament must be used at the higher voltage. Pulse width modulation can be used as an alternative to this method to power 12V incandescent bulbs from a 42V bus.

A semiconductor switch is modified in a pulse-width modulated (PWM) lighting system to apply a periodic pulsed voltage to the lamp filament. The power provided to the filament is dependent on the rms of the applied voltage waveform due to its resistive nature. The system's thermal mass filters the power pulsations to produce light and a filament temperature that are comparable to those produced by a dc voltage with the same rms value. PWM frequencies in the range of 90-250 Hz are typically used and they are chosen low enough to prevent lamp mechanical resonances and the need for EMI filtering while being high enough to minimise visual flicker.

For a 42V nominal voltage source to produce 14V rms across a bulb, the ideal duty ratio is 11.1%. In reality, variances from this duty ratio are required to account for changes in input voltage and device losses. To lower the input rms current of the module, some suggested systems operate many lamps within a single lighting module using phase-staggered (interleaved) PWM waveforms. Startup is another problem with PWM lighting. Because the filament resistance varies with temperature, incandescent lamps experience an inrush current that is 6–8 times higher than the steady-state value even while operating off a 12V dc source. This inrush affects bulb durability. Even when employing standard PWM soft-start procedures (a ramping up of duty ratio), the additional peak inrush current increase caused by operating from a 42V supply may be enough to destroy the filament. To employ PWM lighting control effectively, methods for limiting the peak inrush current must be used, such as starting the controlling MOSFET in current-limiting mode.

Even though PWM incandescent lighting technology is still in its infancy, it provides a number of interesting benefits in 42V automobiles of the future. These include low-cost incandescent lighting conversion to high-voltage systems, control of lighting intensity unaffected by bus voltage, implementation of multiple intensities, flashing, dimming, etc.

through PWM control, and potential enhancement of lamp durability through more exact inrush and operating control.

Piezoelectric Ultrasonic Actuators: In automobiles, piezoelectric ultrasonic motors are being explored as actuators for head restraints, seat adjustment, and window lifts. These motors operate on the idea of transforming ultrasonic vibrations caused by piezoelectricity in an elastic body into unidirectional motion of a moving portion. Power is supplied from the vibrating body to the moving part by frictional contact, and unidirectional motion is achieved by permitting the vibrating body to make contact with the moving part only during a half-cycle of its oscillation. High torque density, huge holding torque even without input power, low speed without gears, quiet operation, no magnetic fields, and high dynamics are just a few of the appealing characteristics of ultrasonic motors . Due to these features, ultrasonic motors are a desirable substitute for electromagnetic motors in low-power, high-torque applications.

Ultrasonic Motors Come in A Variety of Designs.

The travelling wave type is the most used ultrasonic motor, nevertheless, due to its small size. Figure 3(a) depicts the fundamental design of such a motor. It is made up of a metal stator and rotor that are forced into contact with one another by a spring. To improve friction and decrease wear at the contacting surfaces, the rotor is coated with a specific lining substance. The underside of the stator is coated with a piezoelectric substance, such as lead zirconated titanate (PZT). The piezoceramic ring has silver electrodes printed on both sides of it. According to Figure 3(b), the piezoceramic is polarised and the top electrode is segmented with twice as many segments as the excited vibration mode. The downwardly poled segment elongates and the upwardly poled segments contract when a positive voltage is placed between terminals A and C. Due to this, the stator waves up at the contracted section and down at the elongated one. The undulations are inverted when the voltage's polarity is reversed. Consequently, a flexural standing wave is produced in the stator when an ac voltage is introduced. The stator is driven at the resonance frequency of the flexural mode to produce a large wave amplitude. Another standing wave is created by an ac voltage between terminals B and C. The second standing wave is 90 degrees out of phase with the previous one due to the spacer segments in the piezoceramic ring. A travelling wave is produced when two standing waves are triggered by ac voltages that are 90° out of phase in time. The travelling

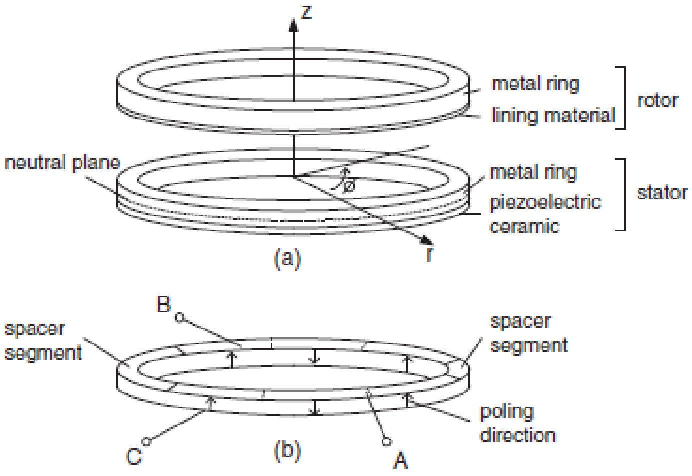

Figure 3: Piezoelectric Ultrasonic Actuators.

wave only experiences axial (z-axis) motion as it passes by a point on the neutral plane. However, there is also an azimuthal (-axis) component of motion for off-neutral plane locations. The rotor is propelled by the azimuthal motion of the surface points. A power electronic drive is necessary for ultrasonic motors. Figure. 4 depicts a power electronic circuit appropriate for powering an ultrasonic motor. In order to produce waveforms that are 90° out of phase with one another, the two H-bridges are controlled.

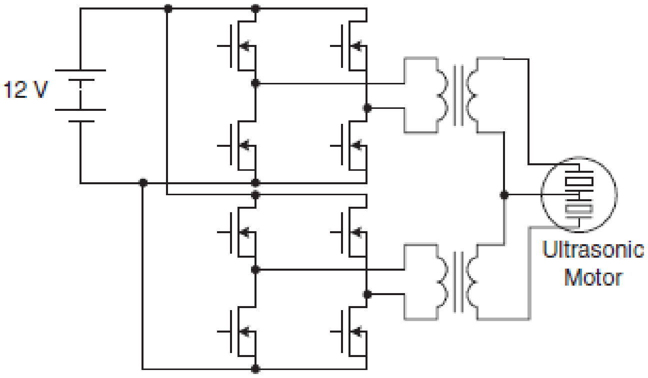

Figure 4: Drive circuit for an ultrasonic motor.

Electric Air Conditioner: It is preferable to swap out some of a vehicle's engine-driven operations for electrically powered alternatives. Eliminating belts and pulleys, improving design and control due to independence from engine speed, and resulting in better efficiency and improved fuel economy are all advantages of driving these functions electrically. Additionally, the function has the option of being used when the engine is off.

An engine-driven system that could benefit from electrification is the air conditioner. The air conditioner's compressor is powered by the engine. Because of this broad range in the compressor's speed, it is necessary to oversize the compressor in order to achieve the desired performance at engine idle. Additionally, because the compressor speed is based on engine speed, excessive cooling occurs at highway speeds, necessitating the mixing of cool and hot air to maintain the proper temperature. Rubber hoses and shaft seals can also cause refrigerant (CFC) loss and present an environmental risk.

The compressor of an electric air conditioner is driven by an electric motor. Typically, a three-phase MOSFET bridge drives a three-phase brushless dc motor. An electric air conditioner's compressor speed is independent of engine speed. The compressor does not need to be overly large as a result, and excessive cooling is avoided. A hermetically sealed system can also be used to replace shaft seals and hoses. An additional advantage of an electric air conditioner is site freedom because it does not require an engine for power.

Electric and Electrohydraulic Power Steering Systems: Another illustration of an accessory powered by an engine is the hydraulic power steering system of a car. A brushless dc motor is utilised to supply the steering power aid in an electric power steering (EPS) system, which can take the place of the current setup. Because the motor only runs when necessary, as opposed to the engine-driven hydraulic steering pump, which is always powered by the engine, the electric power steering system is more efficient than the hydraulic power steering system. The electrohydraulic power steering (EHPS) system is another alternative to the hydraulic power steering system.

In this situation, the hydraulic steering pump can be driven by a brushless DC motor and inverter. When compared to a typical hydraulic system, the EPHS system can drive the pump only when necessary, saving up to 80% of the energy used by the pump. The implementation of EPS and EPHS systems has difficulties in achieving the necessary levels of cost and reliability for this crucial vehicle component.

Motor Speed Control: Variable speed control is necessary for several of the motors found in automobiles. As an illustration, think about the blower motor that moves air into the passenger area. This motor often has a squirrel-cage fan and is a permanent magnet dc motor. The resistance that is linked in series with the motor winding is typically changed to control the speed of the motor.

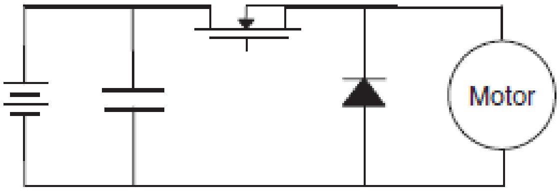

Figure 5: Low-loss circuit to control the speed of a motor.

There is a considerable power loss as a result of this speed control technique. Semiconductor devices are used in a low-loss speed control technique, as depicted in Figure 5. In this instance, the MOSFET is turned on and off with a varied duty-ratio for a variety of speed settings to regulate the speed of the motor using PWM. To decrease the EMI created by the MOSFET switching, an input filter is required. This speed control technique is analogous to giving the motor power via a variable-output dc-to-dc converter. Since the converter is situated near the motor, there is no need for a filter to be placed between the converter output and the motor winding. A three-phase brushless dc motor is utilised as another low-loss technique for controlling a motor's speed. In this scenario, the dc-to-three-phase-ac converter that powers the motor is controlled by modulating the MOSFETs.

Importance of Power Electronics in Electromechanical Power Conversion: Power electronics is a crucial component of electromechanical power conversion, which transforms electrical energy into mechanical energy or the other way around. Energy-efficient and dependable power conversion systems have been made possible by the development of power electronics, opening up a wide range of applications in sectors like transportation, renewable energy, and industrial automation. Electric cars (EVs) and hybrid electric vehicles (HEVs) are two major electromechanical power conversion applications of power electronics. These cars' powertrains transform and regulate electrical power using power electronics components like inverters, DC/DC converters, and motor controllers. In electric vehicles (EVs), the power electronics components are used to convert the battery's DC power to AC power, which is then utilised to regulate the electric motor's speed and torque. A more effective use of energy is made possible in HEVs by the power electronics components, which are utilised to regulate the power flow between the battery and the internal combustion engine.

Renewable energy systems like wind and solar power are yet another area where power electronics is used in the electromechanical power conversion process. The DC electricity produced by these systems is converted into AC power that may be used in homes and businesses using power electronics components like inverters and converters. Additionally, power electronics makes it possible to regulate these systems' power output for maximum effectiveness and efficiency. In industrial automation systems, where electrical power is transformed into mechanical power to control machinery and equipment, power electronics are also crucial. In these systems, the speed and torque of electric motors are controlled by power electronics components, such as variable frequency drives (VFDs), allowing for precise control and increased efficiency. In industrial automation systems, power electronics also makes it possible to regenerate electrical energy while braking, increasing energy efficiency and lowering operational costs.

Power electronics are employed in numerous more applications, including electric trains, lifts, and robots, in addition to the ones already mentioned. These systems can work more effectively and dependably thanks to power electronics components, which enable the efficient conversion of electrical power to mechanical power. The demand for more effective and environmentally friendly power conversion systems serves to further emphasise the significance of power electronics in electromechanical power conversion. There is an increasing need for power conversion systems that are more effective and emit fewer pollutants as people throughout the world become more aware of the negative effects of greenhouse gas emissions on the environment. Power electronics makes it possible to create power conversion systems that are more effective, which lowers energy use and pollutants.

The effective and reliable conversion of electrical power into mechanical power and vice versa is made possible by power electronics, a key technology in electromechanical power conversion. Electric vehicles, renewable energy systems, and industrial automation systems are just a few examples of the many applications that power electronics components are employed in. The demand for more effective and environmentally friendly power conversion systems serves to further emphasise the significance of power electronics in electromechanical power conversion. The future of electromechanical power conversion will depend on developments in power electronics technology as research and development in this field continues [9]–[11].

CONCLUSION

Power electronics has been essential to the growth of the automotive sector. More efficient and ecologically friendly automobiles have been made possible by the use of power electronics in electric and hybrid vehicles. Consumers' overall driving experiences have been improved by the inclusion of power electronics components in safety and infotainment systems. However, there are difficulties in implementing power electronics in the automotive sector. Power electronics parts must be dependable, long-lasting, and economical for the car sector. Future power electronics research will continue to concentrate on enhancing component efficiency and reliability, lowering costs, and creating new applications in the automobile sector.

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CHAPTER 19

POWER ELECTRONICS FOR RENEWABLE ENERGY SOURCES

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ABSTRACT:

A key element in the use of renewable energy sources is power electronics. It is crucial for the conversion, conditioning, and management of energy produced by renewable resources like sun, wind, hydropower, and biomass. The use of power electronics in renewable energy systems is covered in this chapter. The fundamental ideas of power electronics are discussed in the chapter, along with their use in renewable energy systems and its advantages.

KEYWORDS:

Grid-tied Solar Energy Pv System, Hybrid Solid Energy Power System, Renewable Energy Source

INTRODUCTION

The design, management, and use of electronic devices to manage and control electrical power constitute the field of power electronics, which falls under electrical engineering. The ability to convert, condition, and control electricity generated from renewable energy sources so that it is fit for use by consumers is one of the key functions of power electronics, which is why its integration into the power grid is so important. It is difficult to integrate renewable energy sources into the power grid and provide steady electricity to end consumers since they produce electricity in an intermittent and variable way. Examples of such sources are solar, wind, hydro, and biomass. By enabling the effective conversion of renewable energy sources into usable electrical energy, conditioning the power to match the needs of the load, and controlling the flow of power to maintain stable power supply, power electronics technology offers a solution to these problems. Power electronics provide many advantages when used in renewable energy systems, including higher efficiency, lower costs, and a smaller environmental effect. For instance, the adoption of smaller, more cost-effective, and efficient power conversion devices helps to increase the overall efficiency of renewable energy systems. Additionally, it makes it possible for energy storage systems, which are essential for controlling the intermittent nature of renewable energy sources. These systems permit the storing of extra energy produced during peak periods and its release during times of low energy generation [1], [2].

Different renewable energy sources employ power electronics in various ways. Power electronics technology is used in solar energy systems to change the direct current (DC) produced by the solar panels into alternating current (AC), which is used by customers and the grid. Additionally, it adjusts the power so that it satisfies the grid's and the load's needs for voltage and frequency. Power electronics technology is used in wind energy systems to regulate the speed of the wind turbine, making sure that the generator runs at a steady speed regardless of wind speed. Additionally, it changes the generator's fluctuating frequency and voltage output into a stable AC power output. Power electronics technology is employed in hydroelectric energy systems to regulate the generator's output voltage and frequency and safeguard it from overload-related damage. Power electronics technology is utilised in biomass energy systems to transform the biogas produced by the biomass into useful electrical energy.

Although using power electronics technology in renewable energy systems has many advantages, there are drawbacks as well. These difficulties include problems with power quality, voltage swings, harmonic distortions, and the requirement for energy storage devices. By offering solutions like voltage regulation, harmonic filtering, power factor correction, and energy storage devices, power electronics technology can address these issues. The provision of consistent and dependable electricity to end consumers and the integration of renewable energy sources into the power grid both depend on power electronics technology. Power electronics provide many advantages when used in renewable energy systems, including higher efficiency, lower costs, and a smaller environmental effect. To fully realise its potential, however, the issues related to its utilisation must be resolved. To reach a sustainable and greener energy future, power electronics technology must continue to advance and be used in renewable energy systems.

The Kyoto Protocol's goal of reducing greenhouse gas emissions on a global scale has rekindled interest in renewable energy sources all around the world. Today’s renewable energy technologies are widely available, dependable, and competitively priced with those powered by traditional fuels. As demand and supply rise, the cost of renewable energy technology is predicted to continue to decline. There are numerous RES, including tidal, solar, wind, biomass, and small amounts of hydroelectricity. The emphasis in this chapter will be on solar photovoltaic and wind power since these energy sources employ cutting-edge power electronics technologies. The capability of (RES) to deliver sustainable electricity in regions not covered by the traditional power system is one of their benefits. Power electronics are becoming increasingly necessary as a result of the expanding market for renewable energy technology. Electricity electronics and control equipment are needed to convert DC electricity from the majority of renewable energy systems into AC power.

To change from DC to AC, inverters are utilised. Inverters can be either stand-alone or connected to the grid. Both types have a number of characteristics, but their control mechanisms are distinct. When using battery storage for off-grid applications, an independent inverter is used. The inverters may have extra control features, such as running in parallel with diesel generators and bi-directional operation (battery charging and inverting), when used with backup diesel generators (such as photovoltaic (PV)/diesel/hybrid power systems). The voltage and frequency parameters of the utility-generated power displayed on the distribution line must be followed by grid interactive inverters. Details of stand-alone and grid connected inverters for PV and wind applications are reviewed in this chapter, with the conversion efficiency being a key factor for both types of inverters.

Power Electronics for Photovoltaic Power Systems: The functioning of photovoltaic (PV) power systems, which transform solar energy into useable electrical power, depends on the power electronics technology. In order to address the growing need for clean, renewable energy sources, photovoltaic technology is one of the most promising answers. However, in order to assure effective and dependable operation, complex power electronics systems are needed to convert solar energy into useable electrical power.

A solar panel, usually referred to as a photovoltaic module, a power conditioner, and an optional battery storage system commonly make up PV systems. The solar panel is made up of several solar cells that turn sunlight into direct current (DC) electricity. The solar panel's electrical output, however, is often not sufficient to input into the electrical grid or power the majority of electrical needs. In order to transmit the AC power to the load or the electrical grid, the power conditioning unit is necessary to convert the DC power from the solar panel into AC power. The main component of the PV system that regulates the flow of electricity is the power conditioning unit, sometimes referred to as a DC-DC converter or DC-AC inverter. In order to meet the demands of the load or the battery storage system, the DC-DC converter adjusts the voltage and current of the DC output from the solar panel. The DC-AC inverter transforms the battery's DC electricity into AC power, which is subsequently sent to the load or the electrical grid.

Enhancing the effectiveness, dependability, and flexibility of PV power systems requires power electronics. It makes it possible for the PV system to function at its highest power point, which is when the solar panel produces the most electricity. The DC-DC converter may make sure that the solar panel runs at its best efficiency and generates the most electrical power by monitoring the maximum power point. A consistent and dependable power supply is one of the power electronics' most important roles in PV systems. A solar panel's output may be impacted by variations in temperature, shade, and other environmental elements. To ensure a constant and steady power supply, power electronics may account for these elements by modifying the output voltage and current [3]–[5].

PV systems may also include battery storage devices to store extra energy produced throughout the day for usage when there is little or no sunlight. Power electronics are necessary to control the battery's charging and discharging as well as to control the DC output's voltage and current. PV systems may be more flexible thanks to power electronics, which also increases efficiency and dependability. For instance, a PV system may be built as a standalone system, which runs unconnected to the electrical grid, or as a grid-tied system, which is linked to the grid. These systems can be more easily integrated with the help of power electronics, enabling smooth operation and the flexibility to convert between grid-tied and freestanding modes.

For solar power systems to operate efficiently and dependably, power electronics is a key technology. It makes it possible for PV systems to function at their peak power, account for environmental conditions, and provide steady and reliable power production. Power electronics also offers flexibility in PV system design and operation, enabling grid-tied or independent operation as well as the inclusion of battery storage systems. Photovoltaic power systems are set to overtake other sources of clean, renewable energy as power electronics technology advances.

DISCUSSION

Types of PV Power Systems: Different kinds of photovoltaic (PV) power systems exist, each with unique benefits and drawbacks. The optimal PV system for a given application will rely on a number of variables, including the amount of space available, the amount of energy required, and the location. The four primary kinds of PV power systems standalone, grid-tied, hybrid, and portable will be covered in this chapter**.**

OFF-GRID PV SYSTEMS:commonly referred to as standalone PV power systems, are made to function apart from the electrical grid. They are generally utilised in isolated areas where obtaining a grid connection would be prohibitively expensive or impossible. Solar panels, a battery bank for energy storage, and a power conditioning device to control the DC output's voltage and current make up a freestanding PV system. Standalone systems may need a backup generator at times when there is insufficient solar energy. Careful sizing is necessary to guarantee that the solar panel and battery capacity fulfil the energy requirement of the load. Figure 1 illustrates a stand-alone PV system [6], [7]. The Figure 1 illustrates aStand-Alone PV System.

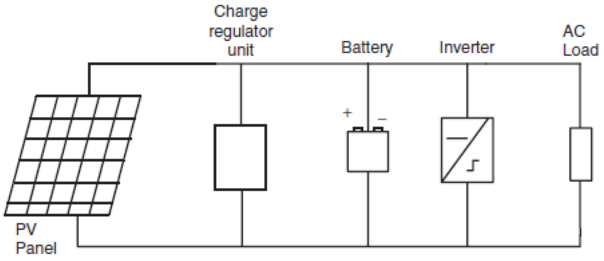

Figure 1:Stand-Alone PV System.

Grid-tied Solar Energy Systems: PV power systems that are grid-tied to the electrical grid are intended to either augment or completely replace the energy provided by the grid. These systems are made up of solar panels, a power conditioner, and a grid-tie inverter that transforms the solar panel's DC output into AC electricity that can be connected to the grid. Urban regions with access to the grid and rules enforcing net metering, which rewards homes for reusing extra energy, are where grid-tied systems are most prevalent. A Grid-connected PV system in Figure 2.

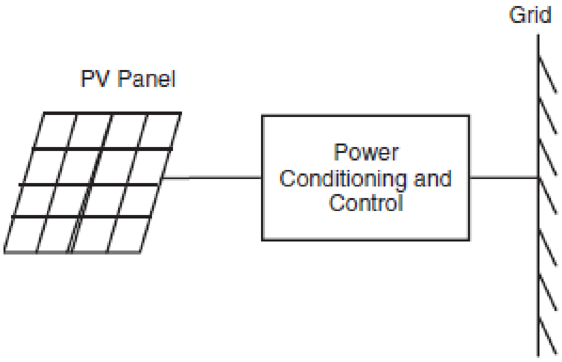

Figure 2: Grid-connected PV system.

Hybrid solar energy systems: Grid-connected and off-grid operation are both possible with hybrid PV power systems since they combine the benefits of standalone and grid-tied systems. A battery bank for energy storage, a power conditioner, and a hybrid inverter that can transition between grid-tied and freestanding modes are often included in these systems. For places with unstable grid supply, where a backup energy source is necessary, or where energy consumption changes throughout the day, hybrid systems are perfect. The Figure 3 shows a hybrid solar energy system.

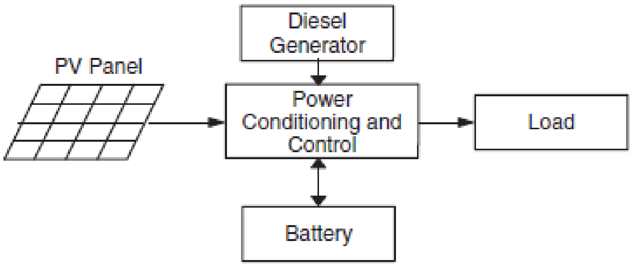

Figure 3: Hybrid Solar Energy System.

PV Power Systems on Wheels: Portable PV power systems are intended for use as emergency backup power and in isolated settings like camping or outdoor gatherings. These systems, which generally include a foldable solar panel, a battery pack, and a power conditioner, are small and light in weight. Additionally, portable systems could include USB connections or other outlets for powering tiny electronic devices.

The four primary kinds of PV power systems are stand-alone, grid-tied, hybrid, and portable. The choice of system relies on a number of variables, including the energy demand, location, and available space.

Each system type has benefits and drawbacks of its own. As power electronics and PV technology continue to advance, more customer choices are becoming accessible, making PV power systems a more attractive source of clean, renewable energy.

Applications of Stand Alone PV system: Off-grid PV systems, usually referred to as standalone PV systems, are intended to provide power in rural locations where grid connection is either impractical or excessively costly. Large commercial and industrial systems as well as modest domestic systems all make use of these technologies in a variety of settings. Following are a few typical uses for freestanding PV systems:

a) **Electricity in Rural Areas:** Rural electrification is one of the most significant uses for freestanding PV systems. A sizable portion of the population in many emerging nations lives in remote, grid-less rural regions. Independent PV systems may provide these communities a dependable and affordable supply of power, enhancing their quality of life by making lights, communication, and other necessities accessible.
b) **Towers for telecommunication:** Many times, telecommunication towers are situated in distant locations without access to the grid. For these towers, standalone PV systems may provide a dependable and independent source of power, assuring continuous communication network functioning. PV systems may lower telecommunication tower running costs by eliminating the need for pricey diesel generators.
c) **A water pump:** Another typical use for standalone PV systems, especially in rural regions, is water pumping. Water pumps that extract water from lakes and rivers or from subterranean sources may be powered by PV systems. This may be used for home water supply, animal irrigation, or irrigation. Desalination facilities may potentially employ standalone PV systems to provide fresh water for coastal communities.
d) **Instrumentation and Remote Monitoring:** Remote monitoring and instrumentation systems, such as weather stations, seismic monitoring systems, or environmental monitoring systems, may be powered by standalone PV systems. In order for these systems to function continually, they need a dependable source of power, which PV systems can provide without the need for regular maintenance or refuelling.
e) **Boats and recreational vehicles:** Recreational vehicles and boats may be powered by standalone PV systems, providing autonomous operation without the need for a generator or grid connection. PV systems may power products like lights, refrigerators, and others, enabling a cosy and environmentally friendly way of life.
f) **Supply of Emergency Power:** During blackouts or natural catastrophes, standalone PV systems may serve as emergency power sources. When the grid goes down, these systems may power crucial items like refrigerators, medical equipment, and communication devices. In distant emergency response scenarios when electricity is required to run vital equipment, stand-alone PV systems may also be deployed.

In summary, freestanding PV systems have many uses in a variety of industries, such as emergency power supply, communications, water pumping, remote monitoring, leisure vehicles, and boats. These systems are an appealing grid connection option because of their adaptability and agility, especially in rural and isolated locations. As PV technology develops, standalone PV systems become more effective, dependable, and affordable, boosting their appeal as a source of clean and sustainable energy.

Applications of Grid-tied Solar Energy PV system: Solar PV systems that are connected to the utility grid are designed to harness solar energy and produce electricity. Large commercial and industrial systems as well as modest domestic systems all make use of these technologies in a variety of settings. Here are a few typical uses for grid-connected solar PV systems:

1. Grid-tied solar energy PV systems are often utilised in residential applications to balance grid electricity use and lower energy costs. These systems, which can produce enough energy to run a house throughout the day, may be mounted on roofs or in backyards. The system's excess energy may be put back into the grid and converted into credits with the utility provider.
2. **Applications in Industry:** Commercial applications are increasingly using grid-tied solar PV systems to balance grid energy demand and save operational expenses. These systems, which can produce enough energy to run a business building throughout the day, may be put on roofs or in parking lots. The system's excess energy may be put back into the grid and converted into credits with the utility provider.
3. Applications in Industry Grid-tied solar PV systems are often utilised in industrial settings to balance grid energy demand and save operational expenses. These systems, which may be mounted on roofs or in open areas, can provide enough energy to run a warehouse or industrial facility throughout the day. The system's excess energy may be put back into the grid and converted into credits with the utility provider.
4. Grid-tied solar energy PV systems are being utilised more and more in agricultural applications to balance out grid energy demand and lower operational expenses. In order to power irrigation pumps, animal watering systems, and other agricultural machinery, these systems may be put on roofs or in open areas. The system's excess energy may be put back into the grid and converted into credits with the utility provider.
5. Community Solar Projects Community solar projects allow numerous homes or businesses to enjoy the advantages of a large solar energy system. Typically, grid-tied solar energy PV systems are employed in these projects. These systems, which may produce enough energy to run a neighbourhood or community, can be deployed in open areas. The system's excess energy may be put back into the grid and converted into credits with the utility provider.
6. **Projects for Utility-Scale Solar:** Utility-scale solar projects, where large solar energy systems produce power to be fed directly into the grid, are increasingly using grid-tied solar energy PV systems. Thousands of homes and businesses may be powered by these systems, which can be deployed in broad, open locations. The system's excess energy may be sold to the utility company, bringing in money for the owner of the solar installation.

Residential, commercial, industrial, agricultural, community solar, and utility-scale solar projects are just a few of the industries where grid-tied solar energy PV systems are used. Grid-tied solar energy PV systems are a desirable alternative for clean and sustainable energy since they may balance grid energy use, save running costs, and perhaps generate income by selling surplus energy to the utility company. Grid-tied solar energy PV systems are becoming more effective, dependable, and affordable as solar technology develops, making them a preferred option for producing power from renewable energy sources.

Applications of Hybrid Solar Energy PV system: Grid-tied and off-grid solar energy systems' advantages are combined in hybrid solar energy PV systems. These systems harness solar power using solar panels and have the capacity to store extra power in batteries for later use. Here are a few typical uses for hybrid solar PV systems:

1. **Housing Applications:** PV hybrid systems are often employed in residential settings to provide dependable and affordable electricity. In order to provide backup power during blackouts and save energy costs during peak hours, these systems may be created to run in both grid-tied and off-grid modes. Batteries may be used to store excess energy produced by the system, guaranteeing a constant supply of energy even when the sun is not shining.
2. **Applications in Industry:** PV hybrid solar energy systems are being employed more often in business settings to provide dependable and affordable electricity. In order to provide backup power during blackouts and save energy costs during peak hours, these systems may be created to run in both grid-tied and off-grid modes. Batteries may be used to store excess energy produced by the system, guaranteeing a constant supply of energy even when the sun is not shining.
3. **Employer-Side Applications:** PV hybrid systems are often utilised in industrial settings to provide dependable and affordable electricity. In order to provide backup power during blackouts and save energy costs during peak hours, these systems may be created to run in both grid-tied and off-grid modes. Batteries may be used to store excess energy produced by the system, guaranteeing a constant supply of energy even when the sun is not shining.
4. **Applications for Distance:** PV hybrid systems for solar energy are often employed in off-grid locations without access to the grid. These systems may be made to work off-grid, supplying dependable and affordable electricity to isolated residences, cottages, and businesses. Batteries may be used to store excess energy produced by the system, guaranteeing a constant supply of energy even when the sun is not shining.
5. **Applications in Telecommunications:** When grid electricity is unavailable, hybrid solar energy PV systems are widely utilised in the telecommunications industry. These systems may be made to function in an off-grid mode, supplying dependable and affordable power for outlying cell towers, radio repeaters, and other communication devices. Batteries may be used to store excess energy produced by the system, guaranteeing a constant supply of energy even when the sun is not shining.
6. **Emergency Response Software:** When dependable and affordable electricity is required in rural regions during catastrophes or disasters, hybrid solar energy PV systems are often deployed. These systems may be created to function in an off-grid mode, supplying emergency shelters, medical facilities, and other vital infrastructure with backup power. Batteries may be used to store excess energy produced by the system, guaranteeing a constant supply of energy even when the sun is not shining.

Residential, commercial, industrial, remote, telecommunications, and emergency response applications are just a few of the industries where hybrid solar energy PV systems are used. Hybrid solar PV systems are a desirable choice for clean and sustainable energy since they can provide dependable and affordable electricity in grid-tied and off-grid modes and have the capacity to store surplus energy in batteries for later use. Hybrid solar energy PV systems are an increasingly common option for producing electricity from renewable energy sources as solar technology develops. They are becoming more efficient, dependable, and cost-effective [8].

CONCLUSION

A key technology for renewable energy systems is power electronics. Power electronics are used in renewable energy systems to increase their performance, dependability, and efficiency. It makes it possible to transform renewable energy sources into usable electrical energy as well as condition the power to meet the demands of the load and manage the power flow. In order to integrate renewable energy sources into the grid and provide a dependable and steady power supply, power electronics technology is crucial. It is clear that using power electronics in renewable energy systems has many advantages, such as higher efficiency, lower costs, and a smaller environmental effect. In order to reach a sustainable and greener energy future, power electronics technology must be developed further and applied to renewable energy systems.

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CHAPTER 20

POWER ELECTRONICS IN WIND TURBINE APPLICATIONS

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ABSTRACT:

In wind turbine applications, power electronics are essential for managing produced power and increasing system effectiveness. In this chapter, rectifiers, inverters, and DC-DC converters as well as other power electronic components utilised in wind turbine systems are discussed. The advantages of power electronics in wind turbines are also discussed, including lower energy costs, better grid integration, and improved system performance. Also discussed the difficulties and potential possibilities for power electronics in wind turbine applications.

KEYWORDS:

Electrical Grid, Multi-Level Convertor, Wind Energy, Wind Turbine, Wind Turbine Applications.

INTRODUCTION

In addition to offering a clean and sustainable substitute for conventional fossil fuels, wind turbines are a form of renewable energy that is growing in popularity. It is difficult to incorporate wind turbines into the electrical grid because of their very unpredictable and sporadic output power. This is where power electronics in wind turbine applications come into play, giving control over the power produced and improving the system's overall efficiency. Power electronics is the use of electronic apparatuses to regulate and transform electrical energy, enabling its more effective utilisation. Electricity electronics are used in wind turbine systems to transform the changing frequency and voltage of the turbine's output into a steady and useful form that can be sent into the electricity grid. Rectifiers, inverters, and DC-DC converters are only a few of the essential power electronic parts used in wind turbine systems. Rectifiers are used to transform turbine-generated AC power into DC voltage, while inverters are used to transform DC voltage into grid-compatible AC voltage. The output voltage of the turbine is matched to the voltage needed by the electrical grid using DC-DC converters [1]–[3].

The potential to lower energy costs is one of the main advantages of employing power electronics in wind turbine applications. Power electronics may assist to maximise the energy produced by the turbine by managing the output power, hence lowering the demand for more turbines and equipment. Power electronics may also aid to increase the system's overall efficiency by lowering energy losses and enhancing system performance. Improved grid integration is a key advantage of power electronics in wind turbines. Power electronics are often used to link wind turbine systems to the electrical grid. This allows for greater control over the power produced and guarantees that it is supplied in a steady and dependable way. As wind power's contribution to the electrical grid increases, this becomes even more crucial since it contributes to system stability and avoids power outages. Despite the numerous advantages of power electronics in applications for wind turbines, there are also difficulties with this technology. The need for dependable and strong components that can survive challenging climatic conditions, such as strong winds, very high temperatures, and exposure to seawater, is one of the major issues. Furthermore, power electronics may be expensive, especially for smaller wind turbine systems.

Future power electronics developments have a tremendous potential for use in wind turbine applications. The development of more sophisticated and effective power electronic components, including novel semiconductor materials, sophisticated control algorithms, and enhanced thermal management systems, is the focus of current research. The efficiency and dependability of the power electronics in wind turbines may be increased, which would lower energy costs and promote the use of renewable energy sources. Power electronics are a crucial part of wind turbine applications because they provide greater control over the power produced and higher system efficiency. Power electronics may be used to save energy costs, promote grid integration, and improve system performance. Despite the difficulties connected with power electronics in wind turbines, there is a lot of room for improvement in this field, which will eventually result in a greater usage of renewable energy sources.

Wind Energy Conversion Systems: The development of wind energy has reached a stage where it is prepared to be used as a standard utility generating technology. The development of the wind turbine from a fringe science in the 1970s to the wind turbine of the 2000s, using the most recent in power electronics, aerodynamics, and mechanical drive train designs, has occurred over the course of the previous 15 years.

The majority of nations have plans to increase the amount of electricity they get from wind energy. It is vital to establish grid-friendly interfaces between the wind turbines and the grid in order to sustain power quality as wind power's proportion in the electric power system rises. Additionally, two things are mostly to blame for the quick advancement of power electronics. The first is the creation of rapid semiconductor switches that can handle large amounts of power and switch quickly. The computer's development as a real-time controller has made it feasible to adopt sophisticated and complicated control algorithms in the control domain, which is the second element. These elements work together to make it feasible to link grid-friendly, budget-friendly converters.

Horizontal-axis Wind Turbine: The technique for obtaining wind energy that is most often employed is a horizontal-axis wind turbine. Large grid-connected wind turbines range in size from a few watts to megawatts in power rating. The rotors are divided into two categories based on their relationship to the tower: leeward (rotor downstream the tower) and windward (rotor upstream the tower), with the latter arrangement being the more common. The rotor, gearbox, and generator make up these turbines. As depicted in Figure.1, the group is completed by a nacelle that houses the mechanisms, as well as a tower that holds the whole system and hydraulic subsystems, electronic control devices, and electrical infrastructure.

The Rotor: The component of the wind turbine known as the rotor is responsible for converting wind energy into mechanical energy. The region where the rotor sweeps is where the wind's energy is collected. The ratio of area to rated power is the indicator of the impact of capturing area size. Therefore, if this ratio is higher, more energy will be provided for the same installed power, resulting in more equivalent hours (kWh/kW). Currently, areas with high average wind speeds (>7 m/s) have values for this ratio that are similar to 2.2 m2/kW, although there is a tendency to raise this ratio to 2.5 m2/kW for certain places with medium and low potential. The high tangential speed at the blade's tip in this instance is the technological limit, which forces the rotors' speed to be reduced. As a result, the variable speed and the technology used are crucial. By correcting for wind loss with a larger capturing area, a larger rotor for a particular wind turbine may be used at locations with lower wind speeds. The rotor is made up of a shaft, blades, and a hub that supports the blades' attachment mechanism to the shaft. The so-called drive train is made up of the rotor and the gearbox. According on whether the kind of tie connecting the blade to the hub is constant or enables rotation around the rotor axis, the rotors may be divided into two broad categories: machines with constant pitch and those with variable pitch [4], [5].

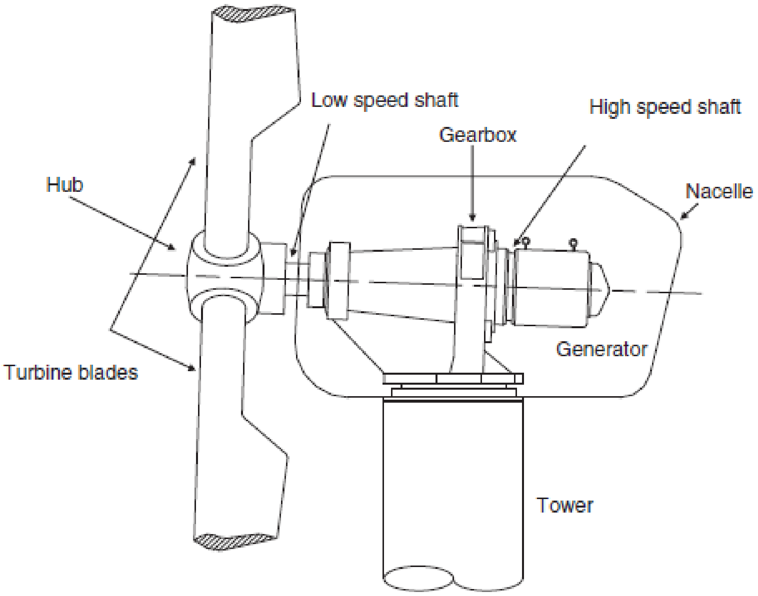

Figure 1: View of Horizontal-Axis Wind Turbine.

A wind turbine's pitch control allows for regulation of energy extraction under high-wind conditions. On the other side, the systems are more costly to design and maintain when variable speed is used. The elimination of abrupt load surges is made possible by the use of variable-speed generators (other than grid generators operating at 50 Hz).This requirement distinguishes between generators with constant speed and those with variable speed. The hub contains both the hydraulic braking system and the blade pitch controller, depending on whether the blade pitch is variable or constant. The axis to which the hub is connected to the so-called low speed shaft is often hollow, allowing for hydraulic conduction for power control by adjusting the blade pitch or, in the event of constant pitch, by operating on the aerodynamic brakes.

The Gearbox: The purpose of the gearbox, as seen in Figure 1, is to convert a low rotor axis rotation speed into a greater one in the electric generator. The axis of the gearbox might be planetary or parallel. The high speed shaft is coupled to the electric generator by a coupler, and it is linked to the low speed shaft by a set of gears. When employing many poles, the gearbox is not always required.

The Generator: The generator's primary goal is to convert the mechanical energy that the wind turbine's rotor has gathered into electrical energy that will be sent into the power grid. In wind turbine systems with constant speed or variable speed control techniques, asynchronous generators are often employed. Additionally, synchronous machines are employed in applications for large-power wind turbines. When the rotor's rotational speed exceeds that of the stator's rotary field, an asynchronous generator produces electrical energy in the stator. To power the rotating field of the stator, the asynchronous generator must draw power from the grid. As a result, the power factor decreases, necessitating the employment of a capacitor bank. Electromagnets in the rotor of the synchronous generator with an excitation system produce the spinning field. By rectifying some of the produced power, a DC current is supplied back into the rotor electromagnets. Permanent magnet generators have also lately been in use. Low power wind turbine applications are the major usage for this kind of machine, which doesn't need an excitation system. Asynchronous generators have cheap cost, reliability, simplicity, and ease of connecting to the grid as positives, but their primary drawbacks are the need for a power factor compensator and a lower efficiency.

Power Electronic Conditioner: The power electronic conditioner is a converter that is mostly used in applications requiring changing speeds. This converter, which supports various frequency and voltage levels in both its input and output, is linked between the generating machine and the utility grid by an isolating transformer. A wound rotor machine's rotor or the stator voltage are linked to the power converter. Large power switches which might be GTOs, Thyristors, IGCTs, or IGBTs are used in this system and are placed in various topologies.

DISCUSSION

Control of Wind Turbines: Pitch control is used to control the rotational speed of many horizontal axes, grid-connected, medium- to large-scale wind turbines. The majority of wind turbines constructed to date have virtually constant speed because they use an AC generator that is directly connected to the distribution grid. Pitch-angle control design has recently included variable speed control in an effort to enhance system performance. A wind turbine that operates at a variable speed offers a number of benefits over one that operates at a constant speed. The main benefits of a variable speed wind tunnel include the potential to reduce stress loads on the blades and mechanical transmissions, the ability to tune the turbine to local conditions by modifying the control parameters, and the potential reduction of electric power fluctuation caused by changes in rotor kinetic energy. Contrarily, relatively few applications have been recorded employing both controls, and variable speed control is often utilised with fixed pitch angle [6]–[8].

According to the controller, four distinct kinds of wind turbines are offered:

a) **No power:** In order to control electricity in strong winds, the generator is directly linked to a grid with a fixed frequency.
b) **Pitch regulation at fixed speed:** In this instance, electricity is regulated in strong winds using pitch control, and the generator is also directly linked to a grid with a steady frequency.
c) **Stall regulation with variable speed:** When the generator is separated from the grid by a frequency converter, the generator reaction torque may be adjusted to change the rotor speed. This speed control function is utilised to slow the rotor down in strong winds until aerodynamic stall restricts the power to the appropriate amount.
d) **Pitch control with variable speed:** By separating the generator from the grid using a frequency converter, it is possible to alter the rotor speed by adjusting the response torque of the generator. Pitch control is utilised to control the rotor speed, which in turn controls the power when there are strong winds.

A power converter will mostly be employed in applications that need varied speeds. A power converter might be utilised in fixed speed control to improve system performance, such as smooth start-up transitions, harmonics, flicker reduction, etc. Following that, the variable speed pitch regulator controller's operation which is the most generic controller is described. This control strategy can yield another controller, but it won't be discussed here.

Variable Speed Variable Pitch Wind Turbine: The following general goals can be used to sum up the purposes of variable speed control systems:

a) To control and smooth the power generated;
b) To maximise the energy captured;
c) To reduce transient loads throughout the wind turbine;
d) To achieve unity power factor on the line side with no low frequency harmonics current injection;
e) To reduce the machine rotor flux at light load; and
f) To reduce core losses.

Pitch-angle control goals are comparable to those for variable speed. A system performs better when pitch-angle control and variable speed are utilised simultaneously. For example, the blade pitch angle is different from the operation pitch angle to enable beginning, enabling simpler starting and optimal running. Additionally, the rotor pitch may be regulated to control the power and speed.

Power Electronic Converters for Variable Speed Wind Turbines: Machines with synchronous or asynchronous motors may have their stator driven by power electronic converters. The rotor of a wound rotor induction machine may be coupled to the power converter in different applications. In the first scenario, the converter manages the machine's total power and works throughout a broad speed range. The converter only manages a small portion of the rated power in the wound rotor machine casing and does not permit a very low speed to maximise wind energy. The power converter has the benefit of being more compact and less expensive than the stator converter.

Full Power Conditioner System for Variable Speed Turbines: The many power electronic converter topologies that are now employed to regulate the broad speed range of generators will be discussed in this section. The following are the benefits and drawbacks of using a wide-range variable speed wind turbine control system as opposed to a narrow-range one. A variable speed wind turbine control system has the benefit of allowing for extremely low speeds to capture more energy from the wind in a given wind range. The power converter must, however, be rated at 100% of the nominal generating power, which is a drawback.

The power conditioners, which will be covered in the next section, may be used to both synchronous and asynchronous generators. The control block that will be used in both situations is specified. For wind energy applications, handling the energy that is acquired from the wind and injected into the grid is the major goal of power converters. When constructing the power converter, consideration must be given to the characteristics of the generator that will be linked to the grid and the location of the electric energy injection. It is required to take into account the kind of semiconductor to be utilised, components, and subsystems in order to achieve this design.

A quick control of the active and reactive power may be achieved together with a low incidence in the distribution electric grid by utilising cycloconverters (AC/AC) or frequency converters based on double frequency conversion, typically AC/DC-DC/AC, and linked by a DC connection. In order to maximise the amount of wind energy gathered while simultaneously enhancing the quality of the energy injected into the electrical grid, the commutation frequency of the power semiconductors is a crucial component in the management of the wind turbine. Because of this, semiconductors with high power limits and high commutation frequencies are necessary. Because of its high breakdown voltage and ability to support commutation rates between 3 and 25 kHz, depending on the power handled by the device, insulated gate bipolar transistors (IGBTs) are often utilised. When utilised in high power applications, other semiconductors like gate turn-off thyristors (GTOs) enable lower commutation frequencies, which worsens both the generator's control and the quality of the energy injected into the electric grid.

The various wide-range rotor speed control topologies are presented next. In terms of power electronics, these topologies have both benefits and drawbacks.

Advantages:

a) Easy conversion and control on the generator side,
b) broad-range speed control,
c) Speed-dependent increases in generated power and voltage,
d) VAR-reactive power control possibilities

Disadvantages:

a) Large DC link capacitors,
b) one or two full-power converters in series;
c) line-side inductance of 10-15% of the produced power;
d) power loss of up to 2-3% of the generated power;

Double Three Phase Voltage Source Converter Connected by a DC-link: The power condition plan for a wind turbine is shown in Figure 2. The three phase inverter on the power converter's left side functions as a driver, vector ally directing the torque generator. The wind energy may be injected into the grid using the three-phase inverter on the right side of the illustration, which also allows for the control of the active and reactive power injected. Additionally, it maintains the lowest feasible overall harmonic distortion coefficient, enhancing the quality of the electricity supplied to the public grid. The DC-link's purpose is to serve as an energy storage system, capturing wind energy, storing it as a charge in capacitors, and instantly injecting it into the grid. The control signal is programmed to keep a steady reference to the capacitor battery's Vdc voltage. We'll go through the control scheme for the grid connection. Both synchronous and asynchronous wind turbine generators may have their speed controlled variably using the power converter seen in Figure. 2.

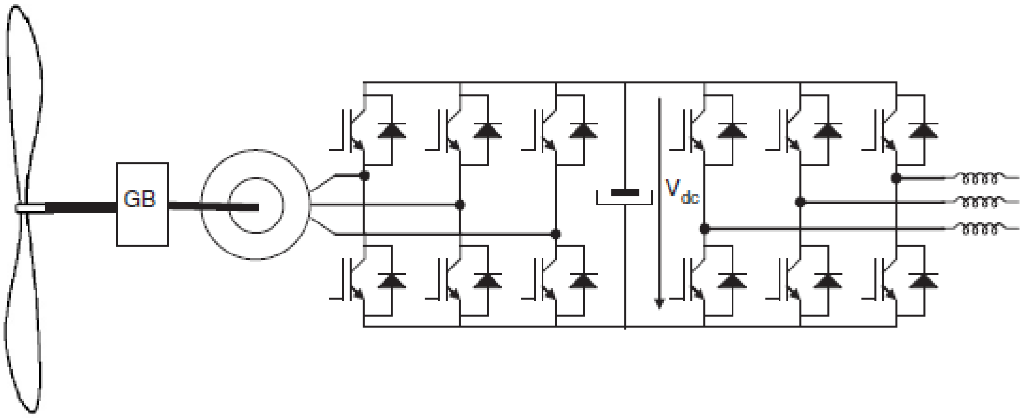

Figure 2: Double three phase voltage source inverter connected by a DC link used in wind turbine applications.

Multilevel Converter for Very High Power Wind Turbines: A major source of renewable energy, wind turbines have been expanding quickly in recent years. The performance and efficiency of wind turbine systems must be increased to meet the rising demand for renewable energy. Multilevel converters are a potential technique for reaching this objective. Power electrical devices known as multilevel converters may provide high-quality output voltage with little harmonic distortion. The use of multilayer converters in extremely high power wind turbines will be covered. Multilevel Converters: The idea behind multilevel converters is to use a series of capacitors to split up a high voltage DC into numerous lower voltage DC levels. The output waveform is then created by combining the voltage levels using switching components like insulated gate bipolar transistors (IGBTs). Higher efficiency, less harmonic distortion, and better output voltage control are just a few benefits of this method.

Application in Wind Turbines: High voltage and high power conversion are needed for very high power wind turbines. For this application, multilevel converters provide an effective and trustworthy solution. They can produce a high-quality output waveform with less harmonic distortion, making them ideal for high voltage applications. By doing so, the system's total efficiency may increase and the stress on the wind turbine can be decreased. The multilevel converter is normally situated between the generator and the grid in a wind turbine system. It is utilised to transform the turbine's fluctuating AC power into a useful form that can be sent into the electrical grid. The output power may also be controlled by the multilayer converter, enabling improved grid integration and the ability to maximise the amount of energy generated.

Benefits of Multilevel Converters: When compared to conventional power electronic systems, multilevel converters provide a number of benefits. They are able to provide output waveforms of excellent quality with little harmonic distortion, which may increase the system's effectiveness and dependability. Additionally, they provide improved output voltage control, enabling more accurate adjustment of the turbine's power output. This may decrease energy losses and increase the system's general efficiency. Scalability is another benefit of multilayer converters. They are suitable for extremely high power wind turbines since they are simple to modify for various power levels. They are suited for use in various renewable energy applications, such as solar and energy storage systems, due to their scalability.

Despite the numerous benefits of multilevel converters, there are still some drawbacks to this technology, Future directions, the cost of the components is one of the major obstacles, especially for systems with extremely high power. The intricacy of the control algorithms necessary to successfully run the converter presents another difficulty. The development of more economical and effective parts as well as more sophisticated control algorithms that can manage the complicated dynamics of extremely high power wind turbines will need to be the main goals of future research in this field. For extremely high power wind turbines, multilevel converters provide an effective and dependable option. They may enhance the efficiency and dependability of the system, provide an output waveform of high quality with less harmonic distortion, and offer improved output voltage control. Despite the difficulties this technology faces, multilevel converters still have a lot of room for improvement. This will eventually result in a greater utilisation of renewable energy sources.

Electrical System of a Wind Farm:A wind farm is a group of wind turbines that use wind energy to produce electricity. The power produced by the wind turbines at a wind farm is collected and sent to the electrical grid via the electrical system. The main elements of a wind farm's electrical system will be covered in this essay.

a. **Wind Turbines:** The electrical system of a wind farm is mostly made up of wind turbines. They take the wind energy and turn it into electricity to fuel their operations. The rotor blades, generator, and power electronics make up the turbines' three primary parts in most cases. The wind's kinetic energy is captured by the rotor blades and sent to the generator, which transforms it into electrical power. Controlling the generator's output and making sure the quality of the energy generated are the responsibilities of the power electronics.
b. **Substation:** The substation serves as the hub of a wind farm's electrical grid. It is in charge of gathering the electrical energy produced by the turbines and converting it into a format that can be sent to the electrical grid across great distances. Transformers, switchgear, and control systems are among the several parts that commonly make up a substation. The transformers boost the power generated by the turbines' voltage to a level that allows for effective long-distance transmission. Between the turbines and the electrical grid, the switchgear regulates the flow of power. The different substation components must be monitored and managed by the control systems.
c. **Power Cables:** The power cables are used to connect the wind farm's turbine-generated energy to the electrical grid. The cables often have many insulating layers and are designed to survive the extreme environmental conditions seen in wind farms. Depending on where the wind farm is located and the topography, the cables are either put on overhead transmission lines or buried underground.
d. **Control and Monitoring Systems:** The control and monitoring systems are in charge of assuring the safe and effective operation of the substation and the wind turbines. The systems, which are used to monitor the different electrical system components and find any flaws or malfunctions, often include a mix of hardware and software. The control systems are also in charge of modifying the turbines' output to guarantee that the quality of the power generated is suitable.
e. **Grid Connection:** The grid connection is the last element of a wind farm's electrical infrastructure. The grid connection is used to link the wind farm to the power grid and enable the distribution of the energy produced by the turbines to customers. The transformer that lowers down the voltage of the power generated by the wind turbines to a level that is compatible with the electrical grid often makes up the grid connection.

The power produced by the wind turbines at a wind farm is collected and distributed by a sophisticated network of components known as the electrical system. The wind turbines, the substation, the power lines, the control and monitoring systems, and the grid connection are the main elements of the system. The effective and safe functioning of the wind farm as well as the delivery of high-quality power to customers depend on the electrical system's proper design and operation [9]–[11].

CONCLUSION

Power electronics are crucial for wind turbine applications because they significantly improve system performance and efficiency while lowering costs. Rectifiers, inverters, and DC-DC converters may be used to manage the electricity generated by wind turbines, improving grid integration and enhancing the amount of energy produced. Power electronics in wind turbines have a number of difficulties, such as the need for durable components that can survive adverse climatic conditions. Future studies in this field should concentrate on creating more sophisticated and dependable power electronics solutions to boost wind turbine performance and efficiency, eventually resulting in a greater usage of renewable energy sources.

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CHAPTER 21

HVDC TRANSMISSION

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ABSTRACT:

With minimal losses, high-voltage direct current (HVDC) transmission technology has emerged as a key technique for moving lots of electricity across great distances. Power electronics are essential in HVDC transmission systems because they enable effective AC to DC power conversion and vice versa, as well as flow management of power. The use of power electronics in HVDC transmission, including converter topologies, control schemes, and applications, is described in this chapter in general terms.

KEYWORDS:

DC Transmission, HVDC Transmission, Power Electronics, Reactive Power, Renewable Energy Source.

INTRODUCTION

The technique of high-voltage direct current (HVDC) transmission has attracted a lot of interest since it allows for the efficient transfer of enormous quantities of electricity across vast distances. Power electronics are used in HVDC systems to manage power flow, convert AC power to DC power, and enhance system performance. An overview of the function of power electronics in HVDC transmission, including converter topologies, control schemes, and applications [1], [2].

Converter Topologies: either converter station at either end of the transmission line makes up the power electronics utilised in HVDC systems. AC electricity is converted to DC power at the converter station, and vice versa. In HVDC systems, the voltage source converter (VSC) and the current source converter (CSC) are the two primary converter topologies. VSCs are often utilised in HVDC transmission systems because to their many benefits, which include a lesser environmental impact, greater efficiency, and increased system stability. Insulated-gate bipolar transistors (IGBTs) and diodes are among the power electronics components that make up a VSC and regulate the flow of power. Better reactive power regulation, which is essential for preserving system stability, is also provided by VSCs. CSCs were often utilised in the past, but owing to their poorer efficiency and bigger footprint, their use has reduced recently. A CSC regulates the flow of electricity using a number of thyristors. Due to its great power handling capability and capacity to manage DC faults, CSCs are still employed in certain applications, such as long-distance submarine power lines.

Control strategies: In HVDC systems, power electronics are also essential for managing power flow and preserving system stability. HVDC systems use a variety of control techniques, such as phase-shift control and pulse-width modulation (PWM). The voltage and current of the DC transmission line are controlled using PWM, a common control approach. It operates by regulating the power electronics devices' duty cycles, which in turn regulate the average voltage and current. PWM enables exact output voltage and current control, which is crucial for preserving system stability and managing power flow. Another control method utilised in HVDC systems is phase-shift control. It operates at the converter station by adjusting the phase angle between the AC voltage and current waveforms. Power flow is managed and system stability is maintained via phase-shift control. When there is a significant power imbalance between the sending and receiving ends of the transmission line, it is very helpful.

Applications include linking power grids, transporting electricity from far-off renewable energy sources, and sending power to offshore oil and gas installations. HVDC transmission systems have a broad variety of uses. Long-distance underwater power cables, which are used to carry electricity between nations, also employ HVDC systems. In order to integrate renewable energy sources and maximise the utilisation of current power generating resources, interconnecting power grids is a crucial application for HVDC transmission systems. Systems for high-voltage direct current (HVDC) transmission may be used to link power grids that run on various frequencies or are not synchronised.

Another significant use of HVDC transmission networks is for the transfer of electricity from distant renewable energy sources. Since distant locations are often home to renewable energy sources like wind and solar energy, it is more effective to transport the electricity over long distances utilising HVDC transmission systems rather than AC transmission methods. Another significant use of HVDC transmission lines is to provide electricity to offshore oil and gas facilities. HVDC transmission systems are an efficient way to provide electricity from onshore sources to these platforms, which need a dependable source. Power electronics play a crucial part in HVDC transmission systems. Controlling power flow and effective conversion of AC power to DC power are all made possible by power electronics.

Transmission of high voltage direct current (HVDC) is a significant application for power electronics. The initial applications of HVDC technology were in the early Gotland (1954) and Sardinia (1967) underwater cable interconnections, and later in long-distance transmission with the Pacific Intertie (1970) and Nelson River (1973) systems employing mercury arc valves. The first back-to-back (BB) asynchronous link between Quebec and New Brunswick took place at Eel River in 1972, marking an important turning point in the development of the technology. This installation also saw the introduction of thyristor valves, which took the place of the previous mercury arc valves. Up till 2005, 95 projects throughout the globe had a combined 70,000MW HVDC transmission capacity built. It is first required to contrast dc transmission with traditional ac transmission in order to comprehend the sudden expansion of dc transmission over the last 50 years [3]–[5].

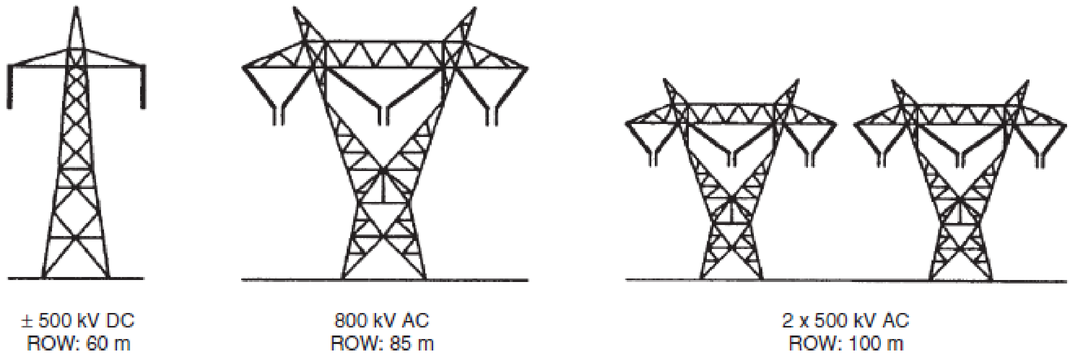

Figure 1: Comparison of ROW for ac and dc transmission systems.

Comparison of AC–DC Transmission: Based on an assessment of transmission costs, technical factors, and the reliability/availability supplied by the two power transmission choices, a planning decision between ac or dc transmission is made.

Evaluation of Transmission Costs:A transmission line's cost consists of the capital expenditure needed for the physical infrastructure (such as right-of-way (ROW), towers, conductors, insulators, and terminal equipment) as well as expenses spent for operating needs (such as losses). A dc line may transport as much power as an ac line with three conductors of same size, assuming that the insulation requirements for peak voltage levels for both ac and dc lines are the same. A dc line has two conductors and has positive/negative polarity with regard to ground. Therefore, a dc line needs less ROW for a given power output, simpler and less expensive towers, and lower conductor and insulator costs. As an example, Figure 1 compares the situation of 2000MW ac and dc systems.

With the DC option, the power transmission losses are also decreased to around two-thirds of the equivalent ac system since there are only two conductors (with the same current capacity as three ac conductors). Additionally, the lack of the skin effect for dc transmission helps to somewhat reduce power losses, and dc transmission also has much lower dielectric losses for power cables. Compared to ac conductors, corona effects on dc conductors are often less prominent. The cost of compensation and terminal equipment are other elements that affect line expenses. Reactive power compensation is not necessary for DC lines, although the cost of the terminal equipment is raised by the presence of converters and filters.

The cost of infrastructure for ac and dc transmission varies with distance, as shown in Figure 2. For lengths under the "breakeven distance," AC is often more cost-effective than DC, but it is more costly for longer distances. This is brought on by the combined price of the two forms of transmission's line and terminal equipment. Depending on the prices per unit of line, the breakeven lengths for overhead lines may range between 500 and 800 km. The breakeven distance for a cable system is close to 50 km.

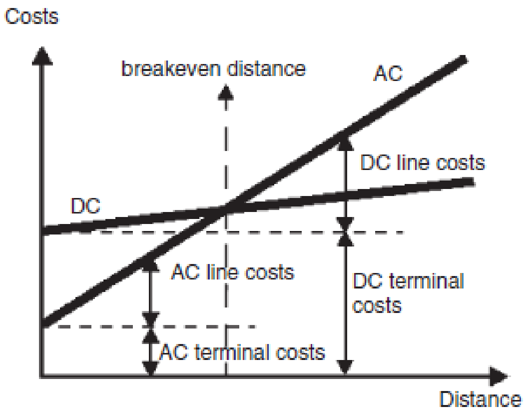

Figure 2: Comparison of ac and dc transmission system costs.

DISCUSSION

Evaluation of Technical Considerations:A dc transmission system has complete control over transmitted power, the ability to improve transient and dynamic stability in connected ac networks, and the capacity to restrict fault currents in the dc lines thanks to its quick controllability. Additionally, some of the following issues with ac transmission are resolved by dc transmission:

Limits to stability: The angular difference between the voltage phasors at the two line ends determines how much power is transferred via an ac line. This angle becomes bigger as you go further for a certain degree of power transmission. The factors affecting steady state and transient stability set a maximum power transfer limit. In contrast to dc lines, which are not impacted by transmission distance, ac lines' capacity to transport power is inversely proportional to transmission distance.

Voltage regulation: Voltage losses and line charging needs make controlling voltage in ac lines difficult. Only at a specific amount of power transmission, which corresponds to its surge impedance loading (SIL), is the voltage profile of an ac line reasonably flat. The line loading affects the voltage profile. When the line loading is more than the SIL, the midway voltage is decreased, and when it is less than the SIL, it is raised. AS the line load increases, reactive power regulation is necessary to maintain constant voltage at both ends. With longer lines, more reactive power is needed. The dc line itself does not need any reactive power, even if dc converter stations do in relation to the power delivered. The breakeven distance for cable transmission is around 50 km because to the steady-state charging currents in ac cables, which present major issues. To get over the issues with line charging and stability restrictions, long-distance ac transmission requires line correction. Shunt inductors, series capacitors, static var compensators (SVCs), and more recently, next generation static compensators (STATCOMs), are used to enhance power transmission and voltage management. Such compensation is not required for dc lines [6], [7].

AC interconnection issues: The automated generation controllers of the two power systems must be coordinated via tie line power and frequency signals in order for them to link to each other through ac ties. The operation of ac ties may be challenging even with coordinated management of linked systems because of (a) the existence of substantial power oscillations that can cause frequent tripping, (b) a rise in fault level, and (c) the transfer of disturbances from one system to another. All of the aforementioned issues are resolved by the quick controllability of the power flow in dc lines. Furthermore, only the usage of dc connections enables the asynchronous linking of two power systems.

Surface impedance: The large magnitude of ground impedance in ac transmission prevents the presence of ground (zero sequence) current in steady state, which not only hinders effective power transfer but also causes telephonic interference. A DC connection may function with a single wire with ground return (monopolar operation) since the ground impedance is insignificant for DC currents. Only when there are underground metallic infrastructure (like pipes) that are vulnerable to corrosion with dc current flow is the ground return unpleasant. Single-pole operation of dc transmission systems is possible for extended periods of time, whereas in ac transmission single-phase operation (or any) unbalanced operation is not feasible for more than a second. It should be noted that even when operating in the monopolar mode, the ac network, feeding the dc converter station, operates with balanced voltages and currents.

a) Problems of DC transmission: The high cost of conversion equipment is one reason that restricts the use of DC transmission.
b) Transformers cannot be used to change voltage levels.
c) Harmonic generation.
d) Reactive power is necessary.
e) Control system complexity.

With the exception of item 2, there have been considerable advancements in dc technology throughout time that have attempted to address the drawbacks outlined above. These include:

a) An improvement in the ratings of a valve's thyristor cell.
b) Thyristor valves are built in a modular fashion.
c) Converters that operate on a 12-pulse cycle.
d) Utilisation of force-commutation.
e) The use of fibre optics and digital electronics for the control of converters.

Some of the aforementioned technological developments have improved dc systems' dependability and decreased their conversion costs.

Applications of DC Transmission: Most dc transmission applications fit into one of the following four groups because of their price and uniqueness:

Underground or underwater cables: The dc cable transmission method has a clear advantage over the ac cable connections for long-cable connections exceeding the breakeven distance of roughly 40–50 km. The Sardinia (1967) and Gotland (1954) plans are examples of this sort of application. Voltage source converters (VSCs), a recent discovery, and the usage of robust polymer dc cables, with the so-called "HVDC Light" option, are being taken into consideration more and more. The 180MW direct link connection in Australia from 2000 serves as an example of this kind of use.

Long distance bulk power transmission: When the breakeven distance is surpassed, dc transmission is more cost-effective than ac transmission for bulk power transfer over large distances. There are several examples of this kind of application, from the historic Pacific Intertie to the more contemporary connections in China and India. With the possibility of developing compact converter stations at lower prices, the breakeven distance is significantly shortened. Because of the most current developments in power electronics (covered in a later section).

Asynchronous interconnection of ac systems: The dc option is the best choice for an asynchronous connectivity between two ac systems. In several BB connections, two ac networks have been linked together for the benefit of both ac systems. These connections are being made more often at weak ac systems as a result of recent advancements in control approaches. The finest illustration of the expansion of BB interconnections may be seen in North America, where 12 BB lines connect the continent's four primary independent power systems. Future plans call for these BB connections to also be established with VSCs, which would allow for full four-quadrant operation, complete active/reactive power regulation, and minimum harmonic production.

Stabilization of power flows in integrated power system: Power flow in ac connections in big linked systems may be out of control and result in overloading and stability issues, putting users in risk (especially when there are disturbances). Systems protection. Due to the quick controllability of dc power, strategically positioned dc lines may solve this issue and provide much-needed dampening and timely overload capability. To assess the advantages, dc transmission planning is necessary in these applications. Examples include the Chandrapur-Padghe connection in India and the IPP link in the USA. Compared to the amount of ac lines, dc lines now make up a relatively minor portion of a power system. This shows that only a limited number of applications are justified for dc transmission. Although multi-terminal dc (MTDC) systems and technological advancements are anticipated to broaden the range of applications for dc transmission, it is doubtful that a dc power grid would ever completely replace the ac grid. This is due to two main factors. First of all, MTDC systems need complicated regulation and safety, and there are financial costs associated with dc networks' incapacity to change voltage. Second, the development of static var systems, static phase shifters, etc. has improved the performance of ac transmissions employing FACTS devices as a consequence of developments in power electronics technology.

Types of HVDC Systems:

Monopolar Link:A monopolar connection (Figure. 3a) employs either ground- or sea-return and has one conductor. Where there are worries about corrosion or harmonic interference, a metallic return may also be employed. A cable return is employed when using dc cables, such as in HVDC lighting applications. A monopolar connection is often operated with negative polarity because the corona effects in a direct current line are significantly reduced when the conductor is polarised negatively compared to positively.

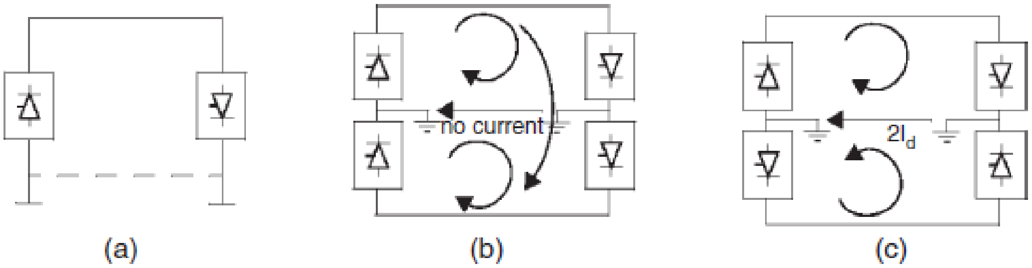

Figure 3: Types of HVDC links: (a) Monopolar link; (b) Bipolar link; and (c) Homopolar link.

Bipolar Link: Two conductors, one with positive and the other with negative polarity, make up a bipolar connection (Figure.3b). Two sets of converters with equal ratings are installed in sequence on the dc side of each terminal. A short electrode line is used to ground the connection between the two sets of converters at one or both ends. Under these circumstances, there is no ground current flowing because both poles run with equal currents in normal operation. Early on in the creation of a bipolar connection, monopolar operation is also an option. Another option is to temporarily utilise one dc line as a metallic return under converter failure situations by using the right switching.

Homopolar Link: Two conductors with the same polarity—typically negative—can be operated with a ground or metallic return in this kind of connection (Fig. 31.3c). Bipolar connections are often employed because running a dc link with ground return is undesirable. Although a homopolar connection offers the benefit of less expensive insulation, the drawbacks of earth return outweigh the benefits.

Main Components of HVDC Converter Station: The converter stations at the endpoints of the transmission system are the main parts of an HVDC transmission system. The conventional two-terminal transmission arrangement needs both an inverter and a rectifier. Since there are often controls at the terminals for both purposes, the roles of the two stations may be switched. Below is a discussion of the key elements of a typical 12-pulse bipolar HVDC converter station (Figure. 4).

Converter Unit:A 12-pulse converter unit is often created by joining two three-phase converter bridges in series. The modular design of valves is based on the idea that each element has a small number of thyristor levels linked in sequence. A single valve, double valve, or quadruple valve configuration may be used to package the valves. Two converter transformers that are coupled in a star/star and star/delta configuration to generate a 12-pulse pair provide the converter. The cooling medium for the valves might be Freon, oil, water, or air. Deionized water cooling, on the other hand, is more contemporary, efficient, and dependable. The permitted short-circuit currents have a greater impact on a valve group's ratings than the steady-state load requirements. At ground potential, valve firing signals are created in the converter control and sent through a fiber-optic light guidance system to each thyristor in the valve. Gate drive amplifiers with pulse transformers are used to turn the light signal received at the thyristor level into an electrical signal. Direct optical firing of the valves using light-triggered thyristors (LTTs) is also possible, according to recent industry developments. Snubber circuits, protective firing, and gapless surge arresters are used to safeguard the valves.

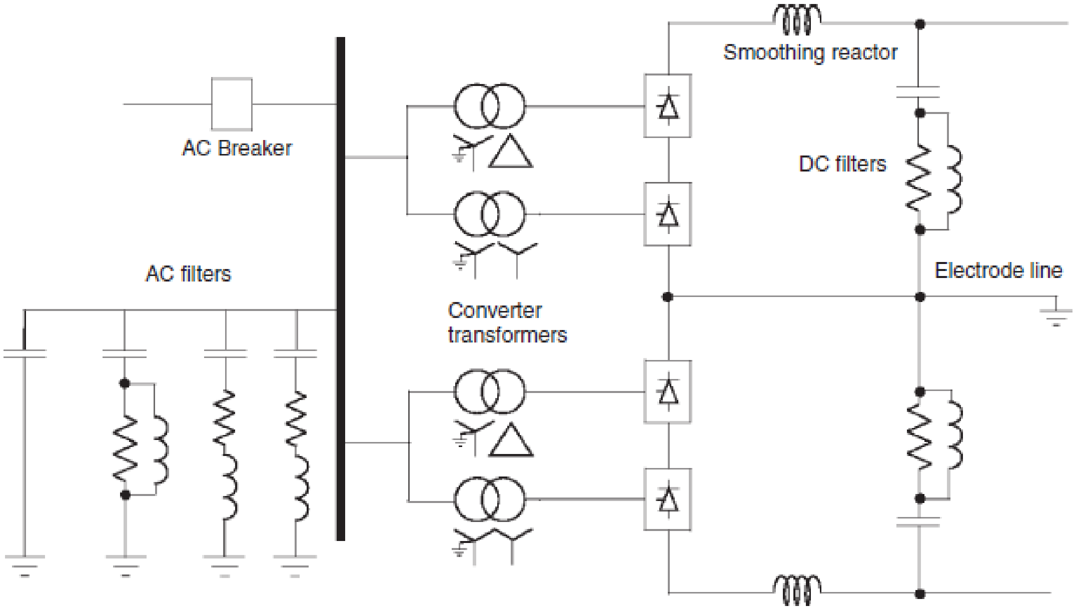

Figure 4: Typical HVDC converter station equipment.

Thyristor valves: An HVDC valve is constructed from several separate thyristors that are linked in series. Special snubber circuits are utilised across each thyristor level to evenly distribute the off-state valve voltage and shield the valve from di/dt and dv/dt stresses (Figure.5).

The following elements make up the snubber circuit:

i. The valve is shielded from di/dt stresses at turn-on by a saturating reactor. The inductance of the saturating reactor is high at low current and low at high current.
ii. A resistor used in dc grading, RG distributes the direct voltage among the several thyristor levels. In order to measure the voltage at the thyristor level, it may also be utilised as a voltage divider. To reduce voltage oscillations from power frequency to a few kilohertz, RC snubber circuits are utilised.
iii. To shield the thyristor level from voltage fluctuations at a much higher frequency, a capacitive grading circuit, or CFG, is utilised.

A firing pulse supplied through a fiberoptic cable from the valve base electronics (VBE) unit located at earth potential activates a thyristor. A gate electronic unit (GEU), which amplifies the fiber-optic signal, gets power from the RC snubber circuit when the valve is off. Also impacted by the GEU the autonomous firing of the thyristor for protection from the main control unit. A breakover diode (BOD) does this through a current-limiting resistor that activates the thyristor when the forward voltage seems to be about to go over the thyristor's rated value. This might happen if some thyristors block forward voltage but not all of them do.

To enable the valve to continue in operation if some thyristors fail, it is typical to incorporate a few extra redundant thyristor levels. For overvoltage protection, a metal oxide surge arrestor is also utilised across each valve. An effective cooling system is crucial since the thyristors lose a lot of heat, approximately 24–40W/cm2 (or more than 1MW for a normal quadruple valve).

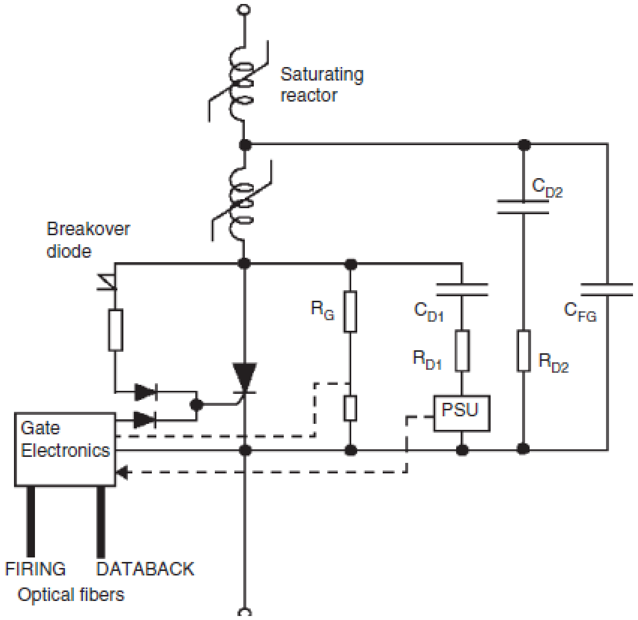

Figure 5: Electrical circuit of the thyristor level

Converter Transformer: Three distinct configurations of the converter transformer are possible: (a) three phase, two winding; (b) single phase, three winding; and (c) single phase, two winding. The neutral point of the star and delta connections between the valve side windings is ungrounded. The transformers are coupled in parallel with the grounded neutral on the ac side. The transformer's leakage impedance, which is typically between 15 and 18%, is selected to restrict the short-circuit currents that may flow through any valve. The converter transformers are designed to resist strains on the dc voltage as well as elevated eddy current losses brought on by harmonic currents. Unsymmetrical valve firing may cause the core to get dc magnetised, which can be a concern.

Filters: To increase the power quality and satisfy telephonic and other criteria, it is required to supply sufficient filters on the ac-dc sides of the converter due to the creation of characteristic and non-characteristic harmonics by the converter. Three different kinds of filters are often used for this purpose.

AC Filters: To offer low impedance, shunt routes for ac harmonic currents, filters are passive AC circuits. There are both tuned and damped filter configurations. Filters at the 11th and 13th harmonics are needed as tuned filters in a conventional 12-pulse station. For the higher harmonics, damped filters are necessary, which are typically set to the 23rd harmonic. Since they provide more affordable designs, C-type filters have also been adopted recently. There are filters that may be double- or even triple-tuned to cut the cost of the filter. Future events will be affected by the availability of affordable active ac filters.

DC filters: These are used to filter dc harmonics and are comparable to ac filters. Typically, a damped 24th harmonic filter is used. Active dc filters are used in modern practise (see also the application example system described later). For efficiency and space savings, active dc filters are increasingly being employed.

High Frequency (RF/PLC) Filters: To stop any high-frequency currents, they are attached between the converter transformer and the station ac bus. Such filters are sometimes offered on both the neutral side and the high-voltage dc bus that connects the dc filter and dc line.

Reactive power source: Reactive power consumption in converter stations depends on the active power loading and is generally between 50 and 60 percent of the active power. One source of this reactive power consumption is the ac filters. Additionally, static var systems and shunt (switched) capacitors are used.

DC Smoothening Reactor: On the converter's dc side, a large series reactor is utilised to both smooth the dc current and protect it from line surges. The reactor may be linked on the line side, neutral side, or at an intermediate point and is often built as a linear reactor. For long distance transmission, the smoothing reactor's typical values fall between 240 and 600 mH, while for a BB connection, they are about 24 mH.

DC Switchgear: This is often modified ac equipment that is used as disconnecting switches to interrupt only very modest dc currents. If necessary, rated load currents are interrupted using DC breakers or metallic return transfer breakers (MRTB). The converter station also includes the above-mentioned equipment as well as ac switchgear and related protection and measuring gear.

DC Cables: Dc cables don't need a constant current of charging as ac cables do when used for transmission. Therefore, the 50 km maximum length restriction does not apply. Additionally, dc voltage results in less ageing and extends the cable's lifespan. ABB's new HVDC light cable design is based on extruded polymeric insulation rather than the traditional paper-oil insulation that has a propensity to leak. Polymer cables may be inexpensively put underground using a ploughing method because of their durable mechanical design, flexibility, and low weight. For underwater applications, they can also be laid in extremely deep seas and on unforgiving seabeds. Very little magnetic field is generated during transmission since dc cables are operated in bipolar mode, with one cable having positive polarity and the other having negative polarity. The functioning of HVDC light cables at a stress of 20 kV/mm has been accomplished effectively [8], [9].

CONCLUSION

Finally, it should be noted that power electronics are essential to the functioning of HVDC transmission systems. They allow for effective AC to DC conversion and vice versa, as well as flow control. In order to enhance system performance, control techniques including pulse width modulation and phase-shift control have been developed. Converter topologies like the voltage source converter and current source converter have been extensively employed in

HVDC systems. Wide-ranging uses for HVDC transmission systems include linking electrical grids, transferring electricity from distant renewable energy sources, and sending power to offshore oil and gas rigs. Power electronics will continue to be crucial in providing effective and dependable HVDC transmission as the need for long-distance power transmission increases.

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CHAPTER 22

FLEXIBLE AC TRANSMISSION

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ABSTRACT:

A group of power electronics tools known as Flexible AC Transmission Systems (FACTS) technology are used to improve the controllability and stability of AC power systems. Existing transmission lines can transmit power more effectively and efficiently thanks to FACTS devices. Additionally, FACTS technology can reduce grid disturbances, dampen power system oscillations, and improve voltage stability. An overview of FACTS technology is provided in this chapter, along with information on its background, several FACTS device kinds, uses, and advantages.

KEYWORDS:

FACTS, Ideal Shunt Compensator, Ideal Series Compensator, Power Flow, Reactive Power.

INTRODUCTION

The complexity and interconnection of the contemporary power system are very high. Power system operators are under a lot of pressure to increase the controllability, stability, and efficiency of the power system due to the rise in electricity demand, the integration of renewable energy sources, and the need for a more resilient and secure grid. In order to accomplish these objectives, flexible AC gearbox systems (FACTS) technology development has been a critical step. A collection of power electronics tools known as FACTS technology can increase the controllability and stability of AC power systems. These tools can be used to increase the voltage stability, reduce oscillations in the power system, and increase the transmission capacity of existing transmission lines. FACTS technology can also improve the flexibility and dependability of the power system and facilitate the incorporation of renewable energy sources [1]–[3].

Hingorani proposed the extensive use of power electronics for the control of ac systems in a paper titled "Power Electronics in Electric Utilities: Role of Power Electronics in Future Power Systems" that was published in 1988. This led to the flexible ac gearbox system, or FACTS concepts. The basic idea was to use self-commutated (controllable turn-on and turn-off) semiconductor devices, such as gate turn-off thyristors (GTOs), insulated gate bipolar transistors (IGBTs), and integrated gate controlled thyristors (IGCTs), which were not yet developed at the time, to create ac systems with a high level of control flexibility, like in high-voltage direct current (HVDC) systems.

Thyristors' controlled turn-on and natural turn-off switching properties are suitable for use in line-commutated converters, such as in customary HVDC transmission systems with a current source in the dc side. Due to the high-voltage properties of the transmission voltage, the technique for series connection of thyristors is crucial in this application. This technology is well-known. Around 8 kV and 4 kA of maximum breakdown voltage and current conduction capacity, respectively. Thyristors have some characteristics that make them crucial for very high-power applications, but they also have some severe disadvantages, like slow switching speeds and a lack of regulated turn-off capability.

Self-commutated switches work well in converters where turn-off functionality is required. The GTO, which has a maximum switching capacity of 6 kV and 6 kA, has long held the record for the device with the highest ratings in this group. Currently, IGBTs with ratings between 6.5 kV and 3 kA and IGCTs with switching capacities of roughly 6 kV and 4 kA are available. Devices like GTOs and IGCTs typically require a tiny inductor to regulate the pace at which the turn-on current (di/dt) changes. Typically, GTOs additionally require a snubber circuit to control the rate of voltage change (dv/dt).

The most popular choices for self-commutated high-power converters are GTOs, IGCTs, and IGBTs. These devices have a more complex series connection than thyristors since their switching times are in the microsecond range (or below). There are examples of series connections between different GTOs or IGCTs, and the number of devices that can be linked in series with an IGBT is up to 32. The converters utilised in HVDC systems are of the current source type because of the commutation nature of thyristors. The force-commutated converters, on the other hand, are mostly of the voltage source type and use self-commutated devices. Numerous power electronics books, such as, provide additional information on current source and voltage source converters.

The evolution of FACTS technology: The research into the use of power electronics devices for regulating the power flow in AC gearbox systems that led to the creation of FACTS technology began in the early 1970s. The Thyristor Controlled Series Capacitor (TCSC), the first FACTS device, was created in the late 1970s and utilised to improve the capacity of long-distance transmission lines for power transfer.Other FACTS devices, including as the Static Var Compensator (SVC), Static Synchronous Series Compensator (SSSC), and Unified Power Flow Controller (UPFC), were created in the years that followed. These devices were created to handle several problems with the power system, including control of power flow, voltage stability, and power oscillations [4]–[6].

FACTS device types: FACTS devices come in a variety of varieties and are employed in numerous applications. Shunt-connected devices and series-connected devices are two categories into which these devices might be divided.

1. Shunt-connected devices can regulate the flow of reactive power since they are linked in parallel with the transmission line. Static Var Compensator (SVC), Static Synchronous Compensator (STATCOM), and Static Synchronous Series Compensator (SSSC) are some examples of these devices.
2. Devices with series connections can regulate the active power flow since they are linked in series with the transmission line. Unified Power Flow Controller (UPFC), Thyristor-Controlled Phase Shifter (TCPS), and Thyristor-Controlled Series Capacitor (TCSC) are some of these devices.

FACTS technology applications include: There are numerous uses for FACTS technology in the electricity system. Among these applications are:

a) Controlling the flow of electricity across a transmission line allows FACTS devices to make the most possible use of the current transmission network. As a result, there may be less need to construct new transmission lines and the line's transmission capacity may rise.

b) **Voltage stability:** By managing the reactive power flow, FACTS devices can make the power system's voltage stability better. By doing so, voltage collapse can be avoided, and power quality can be raised.
c) Power oscillations can be reduced by using FACTS devices, which also increase the stability of the power system. This can enhance the dependability of the electricity grid and prevent blackouts.
d) Grid disturbance mitigation: FACTS technology enhances the power system's resilience by reducing grid disturbances including breakdowns and voltage dips.

FACTS technology advantages include: For the electricity system, FACTS technology offers a number of advantages. These advantages consist of

a) FACTS devices can boost the transmission capacity of already-existing transmission lines, eliminating the need to construct new transmission lines and saving money in the process.
b) Increased voltage stability: FACTS technology can make the power system's voltage more stable, preventing voltage collapse and enhancing power quality.
c) Enhanced power system stability: FACTS devices can reduce oscillations in the power system and increase its stability, minimising blackouts and enhancing the system's dependability.
d) FACTS devices for grid disruption mitigation.

DISCUSSION

Ideal Shunt compensator: A power electronics component called an ideal shunt compensator is used in power systems to enhance the quality of the electricity by managing the flow of reactive power. In order to maintain voltage levels and make sure that the electrical loads receive the necessary power, a power system must have reactive power flow. Reactive power flow, however, can also lead to a number of problems with power quality, including voltage dips, flicker, and harmonic distortion. These problems can be reduced, and the system's power quality can be enhanced, with the ideal shunt compensator [7]–[9].

Two ideal generators make up a straightforward and lossless ac system, and the short gearbox line seen in Figure 1 is used as the foundation for a study of the workings of a shunt compensator. An inductive reactance X_L model is used to simulate the gearbox line. The transmission line in the circuit has a continuously controlled voltage source linked to it. It is assumed that the magnitude and phase shift of the voltage phasors V_S and V_R are equal. "Source" and "Receptor" are indicated by the subscripts "S" and "R," respectively.

The system depicted in Figure.1 is represented by the phasor diagram in Figure.2, where the compensating voltage phasor V_M has the same magnitude as V_S and V_R and has a phase that is exactly $(-\delta/2)$ with respect to V_S and $(+\delta/2)$ with respect to V_R.

In this instance, the current IMR flows into the receptor and the current ISM flows from the source. The voltage source for the ideal shunt compensator does not need to produce or absorb active power; instead, it only needs to have reactive power in its terminals, as shown by the phasor IM in Figure.2, which is the resultant current flowing through the ideal shunt compensator in this case. It is possible to determine the power transferred from V_S to V_R supplied by Figure.2 and the knowledge that no active power flows to or from the ideal shunt compensator.

$$P_S = 2V2/XL. \text{ Sin } (\delta/2)$$

Where P_S is the active power flowing from the source, Vis the magnitude of the voltages V_S and V_R.

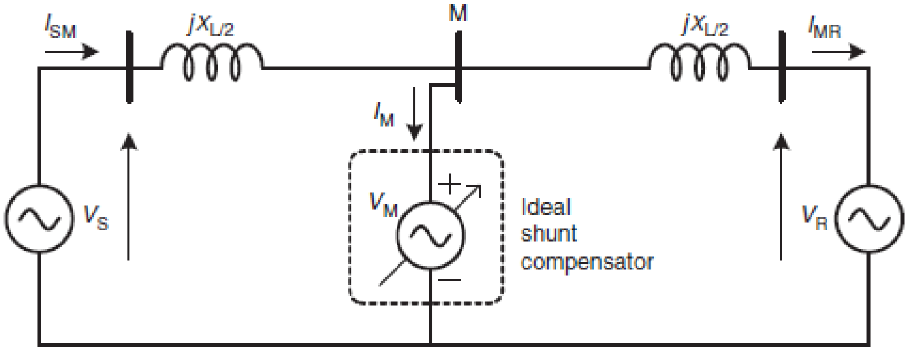

Figure 1: Ideal shunt compensator connected in the middle of a transmission line.

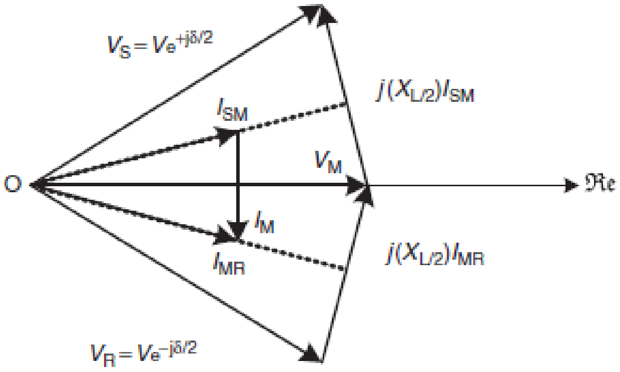

Figure 2: Phasor diagram of the system with shunt reactive power compensation.

If the ideal shunt compensator were not present, the transferred power would be given by

$$PS = V^2/X_L.\ \mathrm{Sin}\ \delta$$

The ideal shunt compensator does enhance the gearbox line's ability to transfer power since 2 sin (δ /2) is always greater than sin for in the range of [0, 2]. In actuality, this voltage source is acting as a perfect shunt compensator for reactive power.

Both active and reactive components of the power are present in the power flowing through VM if the phase angle between VM and VS is not equal to δ /2 (as illustrated in Figure. 3). It is possible to create power electronics-based devices that function as active or reactive power compensators using the qualities of the ideal shunt compensator described above. The parts that follow talk about this. As a result of the need for energy, it will be seen that the specifications for the device synthesis with genuine semiconductor switches for reactive or active power adjustment circumstances are differentstorage element or energy source if active power is to be drained or generated by the shunt compensator.

Working theory: The best shunt compensator affects the power system by adding or taking away reactive power. Capacitors and inductors make up the device, which has the ability to store and release reactive power. The compensator's output voltage can be changed to regulate the flow of reactive power, and it can be linked in parallel with the load or transmission line. The ideal shunt compensator can inject reactive power into the system when the load or gearbox line calls for it, raising voltage levels and lowering voltage drops. On the other side, the perfect shunt compensator can absorb excess reactive power generated by the load or gearbox line, preventing voltage spikes and enhancing power quality.

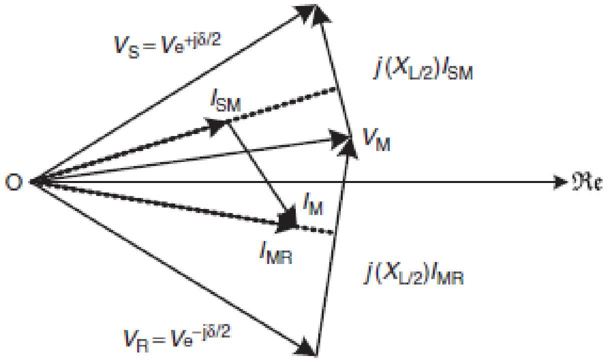

Figure 3: Phasor diagram of the system with shunt reactive and active power compensation.

Ideal shunt compensator types include: Ideal shunt compensators come in a variety of varieties that are utilised in power systems. Passive shunt compensators and active shunt compensators are two categories into which these compensators can be divided. Power electronics are not necessary for passive shunt compensators, which are straightforward devices made of capacitors or inductors that manage the reactive power flow. These compensators lack the ability to control voltage levels and can only inject or absorb reactive power. On the other hand, active shunt compensators control the reactive power flow and regulate the voltage levels using power electronics components like thyristors or IGBTs. Static Var Compensator (SVC) and Static Synchronous Compensator (STATCOM) are two categories into which these compensators fall.

Perfect shunt compensators have the following uses: There are numerous uses for ideal shunt compensators in power systems. Among these applications are:

a) Shunt compensators that work best can control voltage levels and enhance the system's power quality. The electrical loads will receive the necessary power thanks to these compensators, which can also prevent voltage drops and surges.
b) Compensation for reactive power: The best shunt compensators can increase power factor and make up for reactive power flow in the system. This can increase the system's effectiveness and decrease power losses.
c) Harmonic suppression: The system's harmonic currents can be suppressed by ideal shunt compensators, which also enhances the system's power quality. Numerous problems, including equipment overheating and communication system interference, can be brought on by harmonic currents.

The advantages of optimal shunt compensators: Power systems can benefit from ideal shunt compensators in a number of ways. These advantages consist of:

a) Enhanced power quality: By adjusting the voltage levels and reactive power flow, ideal shunt compensators can enhance the power quality of the system. This can lessen harmonic distortion, lessen voltage spikes, and enhance power factor.
b) Enhanced efficiency: By minimising power losses and maximising the utilisation of the current gearbox infrastructure, ideal shunt compensators can enhance the system's efficiency.

c) Improved reliability: By eliminating voltage collapses and decreasing the likelihood of power outages, ideal shunt compensators can improve the system's dependability.
d) Savings: By lowering the demand for new gearbox lines and lengthening the equipment's lifetime by lessening the strain on the electrical components, ideal shunt compensators can reduce costs.

Ideal Series Compensator: An ideal series compensator (Figure 4) is a piece of power electronics that regulates the flow of reactive power to enhance the power quality of power systems. In order to maintain voltage levels and make sure that the electrical loads receive the necessary power, a power system must have reactive power flow. Reactive power flow, however, can also lead to a number of problems with power quality, including voltage dips, flicker, and harmonic distortion. These problems can be resolved and the system's power quality improved by the ideal series compensator.

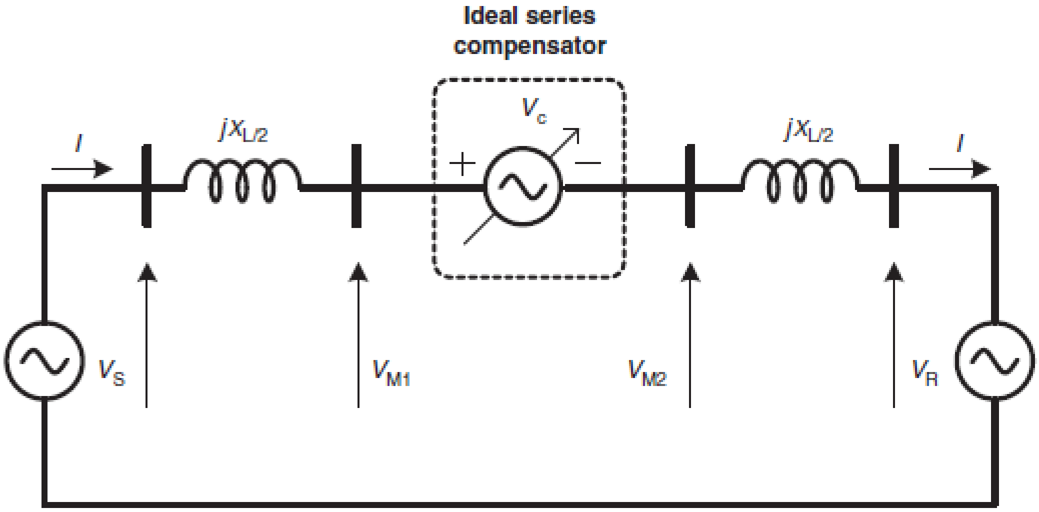

Figure 4: Ideal series compensator connected in the middle of a transmission line.

Working theory: Reactive power is either added to the power system or absorbed by the ideal series compensator. Capacitors and inductors make up the device, which has the ability to store and release reactive power. The compensator's output voltage can be changed to regulate the flow of reactive power when it is connected in series with the transmission line.The perfect series compensator can inject reactive power into the system when the load or gearbox line calls for it, raising voltage levels and lowering voltage drops. In contrast, the ideal series compensator can absorb excess reactive power generated by the load or transmission line, preventing voltage spikes and enhancing power quality.

Various perfect series compensators include: Ideal series compensators come in a variety of varieties that are utilised in power systems. Both passive series compensators and active series compensators can be used to classify these compensators.Power electronics are not necessary for passive series compensators, which are straightforward devices made of capacitors or inductors that regulate the flow of reactive power. These compensators lack the ability to control voltage levels and can only inject or absorb reactive power.On the other hand, active series compensators control the reactive power flow and regulate the voltage levels using power electronics components like thyristors or IGBTs. The Static Synchronous Series Compensator (SSSC) and Unified Power Flow Controller (UPFC) are two categories into which these compensators can be divided [10].

Ideal series compensators have the following uses: Power systems can use ideal series compensators in a variety of ways. Among these applications are:

a) Voltage regulation: The best series compensators can control the voltage levels and enhance the system's power quality. The electrical loads will receive the necessary power thanks to these compensators, which can also prevent voltage drops and surges.
b) Compensation for reactive power: The system's power factor can be raised by using ideal series compensators, which can also account for reactive power flow. This can increase the system's effectiveness and decrease power losses.
c) Control of power flow: By regulating the output voltage, ideal series compensators may regulate the power flow in the gearbox line. This can reduce transmission line congestion and increase the system's overall effectiveness.
d) Limiting fault current in the system can enhance system stability during faults and is a function of ideal series compensators. By doing so, the system's reliability can be increased and it can be kept from tripping.

The advantages of optimal series compensators: Power systems can benefit from ideal series compensators in a number of ways. These advantages consist of:

a) Improved power quality: By managing the voltage levels and controlling the reactive power flow, ideal series compensators can enhance the power quality of the system. This can lessen harmonic distortion, lessen voltage spikes, and enhance power factor.
b) Efficiency gain: By lowering power losses and making the best use of the current transmission infrastructure, ideal series compensators can increase system efficiency.
c) Enhanced reliability: By eliminating voltage collapses and decreasing the likelihood of power outages, ideal series compensators can improve the system's dependability.
d) Saving money: By lowering the demand for new gearbox lines and lengthening the equipment's lifespan by putting less strain on its electrical components, ideal series compensators can reduce prices.

CONCLUSION

Modern power systems can now be improved in terms of performance and stability thanks to FACTS technology. FACTS devices can enhance the voltage profile, reduce oscillations in the power system, and increase the transmission capacity of existing transmission lines. FACTS technology also makes it possible to integrate renewable energy sources, improve the controllability of power systems, and reduce grid disturbances. The need for dependable, secure, and sustainable power systems is likely to grow over time, and FACTS technology is expected to play an increasingly bigger part in transmission and distribution.

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CHAPTER 23

SYNTHESIS OF FACTS DEVICES

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ABSTRACT:

Devices that use the Flexible AC Transmission System (FACTS) have grown in popularity recently because of their enhanced control and stability of the power system. These gadgets, which are electrical, are utilised to regulate the movement of power in transmission systems, enabling effective power transfer. The types, operating systems, and applications of FACTS devices are covered in this chapter. Additionally, it covers the benefits and difficulties of using FACTS devices.

KEYWORDS:

FACTS Devices, Power Floe, Power Factor Correction, Reactive Power, Reactive Power Compensation.

INTRODUCTION

The generation, transmission, and distribution of electrical energy are all accomplished through the power system, which is a sophisticated network of interconnected parts. In order for high voltage electricity to be transmitted to end customers, it must first travel from power plants to substations via the transmission system. But the gearbox system is also vulnerable to a number of difficulties, including voltage instability, poor power quality, and large gearbox losses. Power system engineers have created a variety of tools and technologies that can help the grid become more stable and reliable in order to address these problems. Devices that use the Flexible AC Transmission supply (FACTS) have been increasingly popular in recent years due to their capacity to enhance the control and stability of the power supply. Electronic FACTS devices are used to regulate power flow in gearbox systems, enabling effective power transfer. The transmission capacity of the system is increased by these devices' ability to dynamically alter the voltage, phase angle, and impedance of the transmission line. The types, operating systems, and applications of FACTS devices are covered in this chapter. Additionally, it covers the benefits and difficulties of using FACTS devices [1], [2].

Thyristor-based FACTS devices combine massive energy storage components (capacitors or reactors) with line or natural commutation. Devices based on self-commutating switches, such GTOs, IGCTs, and IGBTs, use gate-controlled commutation in contrast. The first generation of FACTS devices is generally considered to be based on traditional line-commutated thyristors, while the following generations are based on gate-controlled devices or self-commutated switches. The following sections provide information on the most significant FACTS devices based on thyristors and self-commutating devices.

FACTS device types: FACTS devices come in a variety of forms, each with special properties and uses. Among the often-employed FACTS devices are:

a) Static Var Compensator (SVC): SVC is a shunt-connected component that controls the gearbox system's voltage. The voltage is controlled via a thyristor-controlled reactor (TCR) and a thyristor-switched capacitor (TSC), which may swiftly inject or absorb reactive power.
b) Static Synchronous Compensator (STATCOM): STATCOM is another shunt-connected component that controls the gearbox system's voltage. It comprises of a voltage-source converter (VSC) that controls voltage by injecting or absorbing reactive power.
c) A series-connected device called a thyristor-controlled series compensator (TCSC) is used to regulate the transmission line's impedance. The line impedance can be changed using a TCR and a capacitor that can be regulated.
d) Unified Power Flow Controller (UPFC): UPFC is a collection of shunt and series-connected components that can control the gearbox system's voltage and impedance. The voltage and impedance can each be controlled separately thanks to the VSC and TCR-TSC combo that make up the device.

Operating Guidelines: The type and application of a FACTS device will determine how it operates. To increase the system's gearbox capacity, however, the underlying idea behind all FACTS devices is to dynamically alter the voltage, phase angle, and impedance of the gearbox line.For instance, SVC and STATCOM control the voltage of the system by injecting or absorbing reactive power. The transmission line's power flow is altered by the TCSC by altering the line impedance. Voltage and impedance may both be separately controlled by UPFC, giving it complete control over the gearbox system.

Applications: Numerous power system uses for FACTS devices include:

a) **Enhancing Power Quality:** By controlling voltage and lowering harmonics, FACTS devices can assist in enhancing the power quality of the gearbox system.
b) **Reducing Power Losses:** By enhancing the efficiency of the power transfer, FACTS devices can assist in reducing the power losses in the gearbox system.
c) **Increasing Voltage Stability:** By controlling the voltage and preventing voltage collapse, FACTS devices can help the gearbox system's voltage stability.
d) **Increasing Transmission Capacity:** By managing the power flow in the transmission line, FACTS devices can contribute to a system's increased transmission capacity.

Advantages:

a) **Improved Power System Stability:** By controlling voltage and preventing voltage collapse, FACTS devices can aid in enhancing the stability of the power system.
b) **Enhanced Power Quality:** By controlling voltage and lowering harmonics, FACTS devices can make the gearbox system's power quality better.
c) **Reduced Power Losses:** By increasing the efficiency of the power transfer, FACTS devices can lower the power losses in the gearbox system.
d) **Increased Transmission Capacity:** By regulating the power flow in the transmission line, FACTS devices can boost the system's transmission capacity.
e) **Better Control of Power Flow:** FACTS devices enable more effective use of the available transmission capacity by permitting better control of power flow in the transmission line.
f) **Faster Response Times:** The ability of FACTS devices to adapt swiftly to altering system conditions enables them to operate the power system more precisely and promptly.

Challenges:

a) **High Cost:** The installation and maintenance costs of FACTS devices may prevent their general adoption.
b) **Complexity:** FACTS devices are intricate systems that call for specialised training and knowledge to properly design, install, and use.
c) **Potential for Electromagnetic Interference:** FACTS devices have the potential to produce EMI, which can impair the functionality of nearby electronic equipment.
d) **Lack of Standardisation:** FACTS devices are not standardised, which might make it challenging to compare and assess various devices.
e) **Limited Availability:** FACTS devices are still not widely available in many parts of the world due to their high cost and complexity, which may restrict their application in power systems.

DISCUSSION

Thyristor-Based FACTS Devices:

Thyristor-Controlled Reactor:A power electronics component called a thyristor-controlled reactor (TCR) is used in power systems to manage the flow of reactive power. It is a specific kind of FACTS device that is mostly utilised in power systems for power factor correction, voltage management, and reactive power compensation. Thyristors, capacitors, reactors, and control circuits make up the device [3]–[5]. The Figure 1(a) andFigure 1 (b) shows TCR and it V-I waveform.

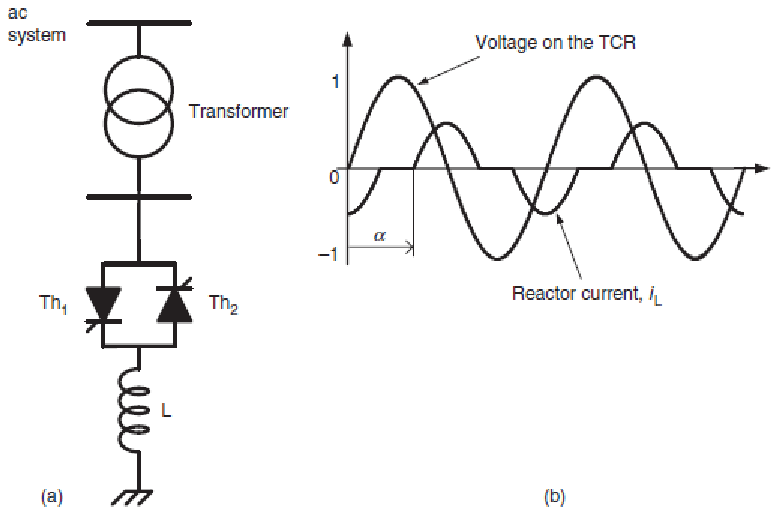

Figure 1: (a) TCR and (b) its voltage and current waveforms.

Working Theory: The ability of the thyristor to switch the reactor's inductance in and out of the circuit underpins the TCR's operation. The thyristors are employed to regulate the reactor's inductance, and the reactor is connected in series with the transmission line. The inductance of the reactor rises when the thyristors are turned on and falls when they are shut off. The voltage across the capacitor and the current flowing through the reactor are measured by the TCR's control circuit. The control circuit modifies the firing angle of the thyristors to produce the desired output by comparing the measured voltage and current to the intended values. The TCR can regulate the amount of reactive power that is injected into or absorbed from the power system by changing the firing angle of the thyristors.

Applications: Reactive power compensation, voltage regulation, and power factor correction are the three main uses of TCRs. TCRs are used for a variety of purposes, such as:

a. **Compensation for Reactive Power:** TCRs are employed to account for the reactive power present in the gearbox. To keep the proper voltage levels in the power system, the gadget can either inject or absorb reactive power.
b. **Voltage Control:** The voltage levels in the power system can be managed using TCRs. In order to control the voltage levels, the gadget can change the reactor's inductance.
c. **Power Factor Correction:** The power system's power factor is adjusted using TCRs. To boost the power factor, the gadget can modify the reactive power flow.
d. **Harmonics:**The use of TCRs for harmonic filtering is possible. By regulating the reactive power flow, the device can lower the harmonic distortion in the power system.

Advantages:

a) **High Efficiency:** TCRs have a high efficiency and can quickly and precisely compensate for reactive power.
b) **Low Maintenance:** TCRs are an economical choice for reactive power correction because of their straightforward design and minimum maintenance needs.
c) **Compact Size:** TCRs are perfect for usage in limited locations due to their compact footprint.
d) **Rapid Response:** TCRs can provide prompt and precise reactive power correction in response to changes in the power system.
e) **Flexible Operation:** TCRs offer flexible reactive power compensation because they can function in both capacitive and inductive modes.

Challenges:

a) TCRs have the potential to produce harmonics in the power system, which could interfere with nearby electronic equipment.
b) Limited Voltage Control: TCRs may not be appropriate for applications requiring precise voltage regulation because to their limited voltage control capacity.
c) TCRs have a restricted control range and might not be appropriate for applications requiring a broad range of reactive power adjustment.
d) High Cost: Installing and maintaining TCRs can be costly, which makes them less cost-effective for small-scale applications.

In summary, TCRs are a class of power electronics device that has the ability to control the amount of reactive power flowing through the power system. Reactive power compensation, voltage control, and power factor correction may all be accomplished using this device's straightforward design and quick, precise reactive power compensation at a reasonable price. TCRs, however, have a restricted voltage control range and can cause harmonics in the power supply, which may make them inappropriate for particular applications [6]–[8].

Thyristor-Switched Capacitor:A power electronics component called a thyristor-controlled reactor (TCR) is used in power systems to manage the flow of reactive power. It is a specific kind of FACTS device that is mostly utilised in power systems for power factor correction, voltage management, and reactive power compensation. Thyristors, capacitors, reactors, and control circuits make up the device shows in Figure 2.

Working Theory: The ability of the thyristor to switch the reactor's inductance in and out of the circuit underpins the TCR's operation. The thyristors are employed to regulate the reactor's inductance, and the reactor is connected in series with the transmission line. The inductance of the reactor rises when the thyristors are turned on and falls when they are shut off. The voltage across the capacitor and the current flowing through the reactor are measured by the TCR's control circuit. The control circuit modifies the firing angle of the thyristors to produce the desired output by comparing the measured voltage and current to the intended values. The TCR can regulate the amount of reactive power that is injected into or absorbed from the power system by changing the firing angle of the thyristors.

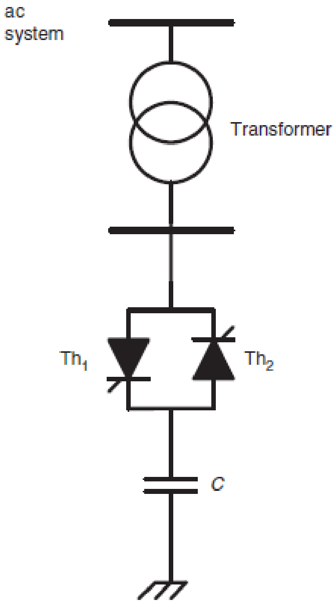

Figure 2: Thyristor-switched capacitor.

Applications: Reactive power compensation, voltage regulation, and power factor correction are the three main uses of TCRs. TCRs are used for a variety of purposes, such as:

a) Compensation for Reactive Power: TCRs are employed to account for the reactive power present in the gearbox. To keep the proper voltage levels in the power system, the gadget can either inject or absorb reactive power.
b) Voltage Control: The voltage levels in the power system can be managed using TCRs. In order to control the voltage levels, the gadget can change the reactor's inductance.
c) Power Factor Correction: The power system's power factor is adjusted using TCRs. To boost the power factor, the gadget can modify the reactive power flow.
d) The use of TCRs for harmonic filtering is possible. By regulating the reactive power flow, the device can lower the harmonic distortion in the power system.

Advantages:

a) High Efficiency: TCRs have a high efficiency and can quickly and precisely compensate for reactive power.
b) Low Maintenance: TCRs are an economical choice for reactive power correction because of their straightforward design and minimum maintenance needs.
c) Compact Size: TCRs are perfect for usage in limited locations due to their compact footprint.

d) Rapid Response: TCRs can provide prompt and precise reactive power correction in response to changes in the power system.
e) Flexible Operation: TCRs offer flexible reactive power compensation because they can function in both capacitive and inductive modes.

Challenges:

a) TCRs have the potential to produce harmonics in the power system, which could interfere with nearby electronic equipment.
b) Limited Voltage Control: TCRs may not be appropriate for applications requiring precise voltage regulation because to their limited voltage control capacity.
c) TCRs have a restricted control range and might not be appropriate for applications requiring a broad range of reactive power adjustment.
d) High Cost: Installing and maintaining TCRs can be costly, which makes them less cost-effective for small-scale applications.

In summary, TCRs are a class of power electronics device that has the ability to control the amount of reactive power flowing through the power system. Reactive power compensation, voltage control, and power factor correction may all be accomplished using this device's straightforward design and quick, precise reactive power compensation at a reasonable price. TCRs, however, have a restricted voltage control range and can cause harmonics in the power supply, which may make them inappropriate for particular applications.

Static Var Compensator: Power electronics equipment called the Static Var Compensator (SVC) is used in power systems to control voltage and enhance power quality. It is a particular kind of FACTS device that compensates for reactive power by regulating the voltage and current in the power system. The Figure3 illustrates the six pulses SVC.

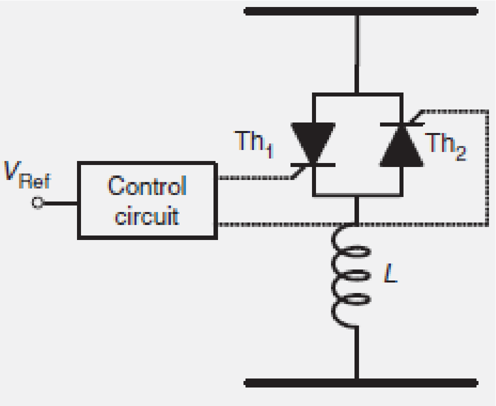

Figure 3: Six-Pulse SVC.

Working Theory: The ability of the thyristor to switch reactive components in and out of the circuit underpins the operation of an SVC. Reactor, capacitor bank, and thyristors make up the device. The capacitor bank is linked in parallel with the transmission line, while the reactor is connected in series with it. In order to provide the desired output, the control circuit of an SVC monitors the voltage and current in the gearbox line and modifies the firing angle of the thyristors. The SVC can regulate the amount of reactive power that is injected into or withdrawn from the power system by changing the firing angle of the thyristors.

Applications: Reactive power compensation, voltage regulation, and power factor correction are the three main uses of SVCs. SVCs are used for a variety of purposes, such as:

a) Compensation for Reactive Power: Transmission lines' reactive power is taken into account by SVCs. To keep the proper voltage levels in the power system, the gadget can either inject or absorb reactive power.
b) Voltage Control: SVCs can be used to regulate the power system's voltage levels. To control the voltage levels, the device can change the inductance of the reactor or the capacitance of the capacitor bank.
c) SVCs are employed for power factor correction in the electrical system. To boost the power factor, the gadget can modify the reactive power flow.
d) Flicker mitigation is a possible application for SVCs. The gadget can lessen voltage fluctuations brought on by heavy loads or abrupt power system changes.

Advantages:

a) **High Efficiency:** SVCs have a high efficiency and can quickly and accurately compensate for reactive power.
b) **High Control Range:** Because SVCs have a broad control range, they are appropriate for applications requiring a variety of reactive power adjustment.
c) **Improved Power Quality:** By controlling voltage levels and decreasing flicker in the power system, SVCs can enhance power quality.
d) **Rapid Response:** SVCs can provide prompt and precise reactive power compensation in response to changes in the power system.
e) **Flexible Operation:** SVCs offer versatility in reactive power compensation by operating in both capacitive and inductive modes.

Challenges:

a) SVCs have the potential to produce harmonics in the electrical supply, which could interfere with nearby electronic devices.
b) High Cost: SVCs are less cost-effective for small-scale applications since they can be expensive to install and maintain.
c) Limited Space: Because of their enormous size, SVCs are inappropriate for usage in small places.
d) Control Complexity: A competent engineer is required to build and maintain an SVC's sophisticated control circuit.

SVCs, a particular class of power electronics device, have the ability to control how reactive power flows through the power system. The device is an effective method for reactive power compensation, voltage control, power factor correction, and flicker suppression because of its broad control range, high efficiency, and quick response time.

SVCs are less suited for small-scale applications due to their huge footprint, ability to produce harmonics in the power system, and high installation and maintenance costs. SVCs are an important addition to the power system that can boost stability and efficiency.

Thyristor-Controlled Series Capacitor (TCSC):A power electronics component called a thyristor-controlled series capacitor (TCSC) is used in power systems to increase the capacity and reliability of power transmission. Thyristors are used in the TCSC, a form of FACTS (Flexible AC Transmission Systems) device, to regulate the impedance of a series capacitor linked in-line with a transmission line.The Thyristor-Controlled Series Capacitors is shown in Figure 4.

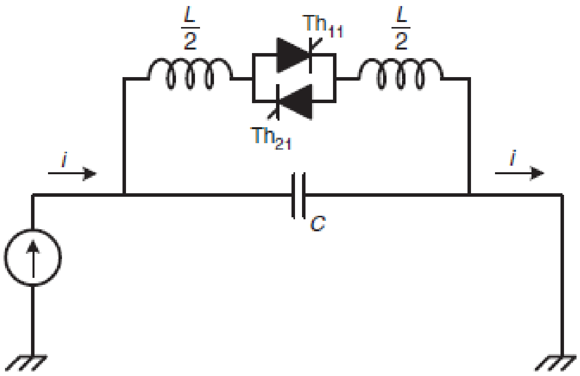

Figure 4: Thyristor-Controlled Series Capacitors.

Working Theory: The ability of the thyristor to regulate the reactance of a series capacitor forms the basis of the operation of a TCSC. A capacitor connected in series with a thyristor-controlled reactor (TCR) makes up the device. The reactance of the capacitor is managed by the TCR, which in turn manages the current flowing through the transmission line. A TCSC's control circuit detects the voltage and current flowing through the gearbox line and modifies the thyristors' firing angle to produce the desired output. The firing angle of the thyristors allows the TCSC to modify the capacitive reactance of the series capacitor and, consequently, the transmission line's impedance.

Applications: Power transmission capacity and stability increase are the main uses of TCSCs. Applications of TCSCs include some of the following:

a) **Control of electricity Flow:** TCSCs are used to regulate the flow of electricity through transmission lines. The gadget has the ability to alter the transmission line's impedance, which in turn affects how much power flows through it.
b) **Voltage Stability:** TCSCs can enhance the power system's voltage stability. By regulating the capacitor's reactance and subsequently the voltage levels, the device may compensate for reactive power.
c) **Damping of Oscillations:** TCSCs can reduce oscillations in the power system brought on by faults or other disturbances. To prevent oscillations, the device has the ability to either inject or absorb reactive power.
d) The load on various transmission lines can be balanced by using TCSCs. To rebalance the power flow, the gadget can change the line's impedance.

Advantages:

a) Enhancement of Power Transmission Capacity: TCSCs can improve the power system's transmission capacity by lowering the transmission line impedance.
b) **Voltage Stability:** By supplying reactive power correction, TCSCs can increase the voltage stability of the power system.
c) **Damping of Oscillations:** TCSCs can increase the stability of the power system by reducing oscillations brought on by faults or other disturbances.
d) **Rapid Reaction:** TCSCs can deliver prompt and precise power flow regulation in response to changes in the power system.
e) **Flexible Operation:** TCSCs offer versatility in power flow regulation because they can function in both capacitive and inductive modes.

Challenges:

a) **Harmonic Generation:**TCSCs have the ability to produce harmonics in the power supply, which can interfere with nearby electronic equipment.
b) **Control Complexity:** A TCSC's control circuit is intricate, and designing and maintaining the device calls for competent engineers.
c) **Cost:** Installing and maintaining TCSCs can be expensive, which makes them less cost effective for small-scale applications.
d) **Limited Space:** Because of their enormous footprint, TCSCs are inappropriate for usage in small places.

In summary, TCSCs are a class of power electronics device that can improve the power system's gearbox capability and stability. Applications for the device include load balancing, oscillation damping, voltage stability, and regulation of power flow. However, TCSCs are less appropriate for small-scale applications since they can cause harmonics in the power supply, have a large footprint, and can be expensive to install and maintain. In general, TCSCs are a useful addition to the power system and can raise stability and efficiency levels.

Static Synchronous Compensator (STATCOM): In order to increase the stability and control of power systems, a sort of Flexible AC Transmission System (FACTS) device known as a Static Synchronous Compensator (STATCOM) is frequently utilised. To ensure system stability in transient and steady-state situations, STATCOMs offer quick reactive power compensation, voltage regulation, and harmonic reduction. Transformer, DC capacitor, and voltage source converter (VSC) are the three primary parts that make up most STATCOMs (Figure 5).

The reactive power required to stabilise the system is produced by the VSC, which serves as the brain of the STATCOM. Injecting AC voltage into the grid at the desired frequency and phase angle, it transforms the DC voltage from the DC capacitor. Before the AC signal is introduced into the grid, the transformer is utilised to increase or decrease its voltage.The ability of STATCOMs to deliver dynamic voltage support during voltage dips and sags is one of its key features. They have the ability to inject or absorb reactive power to keep the voltage stable and avoid causing equipment damage. By producing or absorbing reactive power, STATCOMs can also assist the system's power factor, which can lower gearbox losses and boost the effectiveness of the power system. The capacity of STATCOMs to reduce harmonic distortion in the power supply is another benefit. Non-linear loads, such as variable speed drives, can result in harmonic distortion, which can damage equipment and have an impact on the quality of the electricity. A cleaner and more reliable power supply is achieved by using STATCOMs to inject or absorb reactive power at particular frequencies in order to cancel out harmonic distortion.

In order to alter the output of the VSC, complex digital control systems are often used to regulate STATCOMs. These systems use real-time measurements of system characteristics like voltage and current. The control system can be programmed to react to particular occurrences like voltage dips or harmonic distortion and can modify the STATCOM output to keep the system stable. STATCOMs are a flexible and useful instrument for enhancing the control and stability of power systems. They are managed by cutting-edge digital control systems and offer quick reactive power compensation, voltage regulation, and harmonic abatement. The importance of STATCOMs in providing a steady and dependable power supply is projected to increase as power systems grow more complex and dynamic.

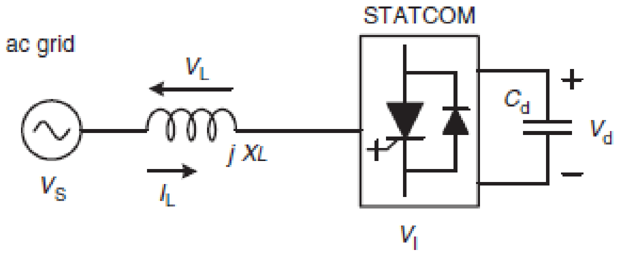

Figure 5: Simplified circuit for the ac grid and the STATCOM.

Applications: To increase the control and stability of power systems, STATCOMs are employed in a number of applications. Examples of typical applications include:

a) In order to maintain a constant voltage level and avoid equipment damage, STATCOMs can offer dynamic voltage support during voltage dips and sags.
b) Reactive power compensation: STATCOMs have the ability to produce or consume reactive power to raise the system's power factor, lower gearbox losses, and boost efficiency.
c) Harmonic mitigation: STATCOMs have the ability to inject or absorb reactive power at particular frequencies in order to balance out harmonic distortion, producing a more dependable and stable power source.
d) Integration of renewable energy sources: By reducing output variations and enhancing power quality, STATCOMs can assist in the integration of renewable energy sources into the electrical grid.

Advantages:

a) Rapid response: STATCOMs are capable of reacting swiftly to modifications in the state of the system, which makes them useful for preserving system stability under transient and steady-state settings.
b) High efficiency: STATCOMs can boost the system's power factor and lower transmission losses, which makes the power supply more effective.
c) Design flexibility: STATCOMs can be created to satisfy particular system needs and are simple to integrate into current power systems.
d) Harmonic distortion reduction: STATCOMs can reduce harmonic distortion in the electrical system, leading in a cleaner and more reliable power supply.

Disadvantages:

a) High cost: STATCOMs may be difficult to use with smaller power systems due to their high installation and maintenance costs.
b) Complexity: The control systems used to run STATCOMs can be challenging to use and necessitate specialised knowledge.
c) STATCOMs have a restricted operational range and may not be able to effectively mitigate all sorts of disruptions.
d) Like any electrical device, STATCOMs are susceptible to environmental conditions like lightning strikes or power surges that can cause damage.

STATCOMs can be used for voltage regulation, reactive power compensation, harmonic mitigation, and the integration of renewable energy sources. They are a useful instrument for enhancing the stability and control of power systems. They have a modular design, excellent efficiency, and quick response times, but are expensive and complex. When building and running power systems, it is important to take into account their limited range and susceptibility to damage.

Unified Power Flow Controller (UPFC):A Flexible AC Transmission System (FACTS) device called the Unified Power Flow Controller (UPFC) is used in power systems to enhance network control and stability. It is a versatile tool that can control power flow, voltage, and phase angle, giving the power system real-time control. A series transformer, shunt transformer, and voltage source converter (VSC) are the three primary parts of a UPFC. The transmission line is connected in series with the series transformer, which is used to manage the phase angle to regulate the power flow. Shunt transformers are used to control voltage by injecting or absorbing reactive power and are linked in parallel with transmission lines. The VSC, which controls both the generation and absorption of reactive power as well as the phase angle of the power flow, is the brains of the UPFC(in Figure 6).

The capacity of UPFCs to independently control both the actual and reactive power flow in the transmission line is one of its key advantages. This enables the device to reduce network congestion and raise the overall effectiveness of the power system. The system can benefit from the UPFC's ability to sustain voltage, which helps keep the voltage level consistent and guard against equipment damage. Another benefit of UPFCs is that they can quickly react to control the power system. The UPFC is a useful tool for preserving system stability during transient and steady-state situations because the VSC can react swiftly to changes in the system's conditions. In addition, by lowering the possibility of cascade failures, UPFCs can increase the reliability of the power system. The tool can assist stop the propagation of defects to other areas of the network by being able to identify and isolate systemic flaws. The high cost and complexity of UPFCs is one of its key drawbacks. The device is more expensive than other FACTS device types since it needs complex control systems and specialised components. In order to make sure it is running efficiently, it also needs routine maintenance.

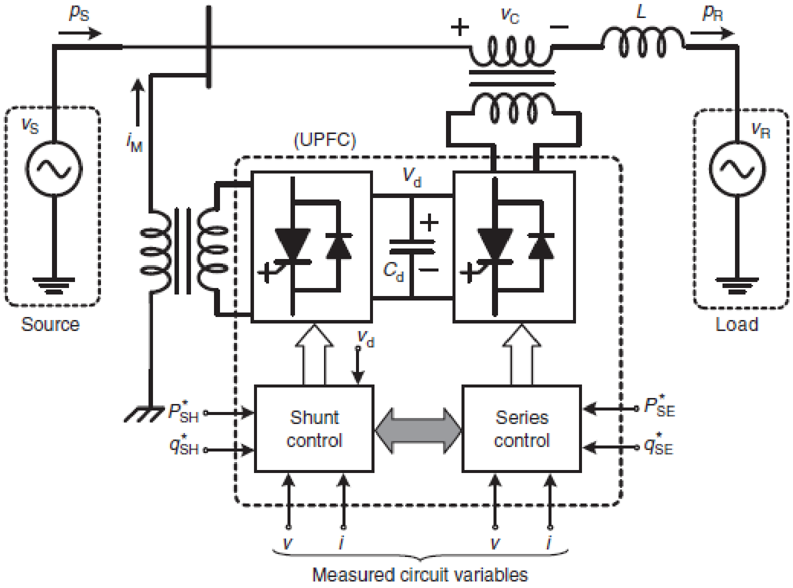

Figure 6: UPFC block diagram.

The susceptibility of UPFCs to errors and damage is another possible drawback. The device can be harmed by external conditions like strong winds or flooding and is vulnerable to lightning strikes and power surges.

The Unified Power Flow Controller (UPFC), in short, is a multi-functional FACTS device that offers independent control of both the actual and reactive power flow in the transmission line.

It can lessen traffic, increase effectiveness, and give the system voltage support. By identifying and isolating defects, UPFCs can help increase the reliability of the electrical system. However, when developing and running power systems, it is important to take into account the device's high cost, complexity, and susceptibility to damage.

Applications: The Unified Power Flow Controller (UPFC) is a flexible and adaptable tool that can be utilised in a number of power system applications, including:

a) Power Flow Control: By adjusting the voltage's phase angle and magnitude, the UPFC may regulate the amount of power flowing through transmission lines.
b) Voltage Control: By injecting or absorbing reactive power, the UPFC may control the voltage level in the power system.
c) Oscillation damping: The UPFC can increase the dynamic stability of the power system and lower oscillations.
d) Fault Isolation: The UPFC can identify and isolate power system defects, preventing fault propagation and enhancing system dependability.

Advantages:

a) Increased Power Transfer Capacity: The UPFC can boost transmission lines' power transfer capabilities, enabling the transmission of more power over long distances without the expense of expensive modifications.
b) Improved Power Quality: By controlling voltage levels and lowering voltage fluctuations, the UPFC can enhance power quality while lowering the chance of equipment damage.
c) Flexibility: The UPFC is a flexible solution for power system control and optimisation since it is simple to reconfigure to meet changing system requirements.
d) Rapid Reaction: The UPFC has a short response time to changes in the system's parameters, which enhances the stability of the power system both in transient and steady-state situations.

Disadvantages:

a) High Price: Compared to other FACTS devices, the UPFC is more expensive due to its complexity, which necessitates the use of sophisticated control systems and specialised components.
b) Complexity: The control systems used to run UPFCs can be challenging to use and necessitate specialised knowledge.
c) Maintenance Requirements: The UPFC needs routine maintenance to make sure it is working properly, which could raise the power system's running expenses.
d) The UPFC is vulnerable to external elements including lightning strikes and power surges, and if it is not sufficiently protected, it could sustain damage.

The UPFC is a flexible and adaptable tool that may be utilised to enhance the control and optimisation of power systems. It has benefits including a higher power transmission capacity, better power quality, adaptability, and quick reaction. However, it also has drawbacks such high cost, complexity, upkeep requirements, and damage susceptibility. When building and running power systems using UPFCs, these factors need to be taken into account [9], [10].

CONCLUSION

Modern power systems cannot function without FACTS devices now, which contribute to the grid's stability and dependability. They can be used for a variety of things, including as strengthening voltage stability, lowering power losses, and improving power quality. Although these devices have many benefits, they also have a number of drawbacks, such as high cost, complexity, and the possibility of electromagnetic interference. Overall, FACTS technology is promising and is anticipated to grow in significance as the need for dependable and effective power systems rises.

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CHAPTER 24

DRIVES REQUIREMENTS AND SPECIFICATIONS

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ABSTRACT:

Drives are machinery that change the mechanical energy contained in electrical energy. They are employed to regulate the torque, speed, and rotational direction of motors in a variety of industrial applications. The market offers a variety of drives, including AC drives, DC drives, servo drives, stepper drives, and others. There are benefits and drawbacks to each style of drive. The many drive types and their features will be covered in this chapter.

KEYWORDS:

DC Drives, Power Factor, Speed Drives, VSD, Variable Speed Drive.

INTRODUCTION

In a variety of industrial applications, drives are components that are used to regulate the speed, torque, and rotational direction of motors. They are employed in the transformation of electrical energy into mechanical energy, which is subsequently applied to the operation of machinery and apparatus. Drives are a crucial part of industrial automation and control systems because they offer precise control over motor speed and torque, guaranteeing the effective and secure functioning of machinery. The market offers a variety of drives, including AC drives, DC drives, servo drives, stepper drives, and others. Each drive type is ideal for particular applications because it has a unique set of benefits and drawbacks. Applications requiring speed control are best served by AC drives, whereas those requiring strong torque at low speeds are best served by DC drives. Stepper drives are utilised in applications demanding accurate positioning, whereas servo drives are used in applications needing great accuracy and precision. Numerous industries, including industrial, automotive, aerospace, and food processing, utilise drives. They are used to power a variety of tools and machinery, including compressors, pumps, fans, and conveyor belts. Drives can help industrial processes run more smoothly and efficiently, which increases production and lowers costs. It is crucial to take into account aspects like power rating, voltage and current ratings, and control mechanisms when choosing a drive. Drives can be controlled in a variety of ways, including open-loop and closed-loop control. Closed-loop control is utilised in situations when accuracy and precision are essential, whereas open-loop control is employed where precise control is not necessary. Drives are essential components of industrial automation and control systems because they enable accurate management of motor speed and torque. The market offers a variety of drive types, each ideal for a particular application. Engineers and technicians may choose the best drive for their applications by being aware of the many drive types and their parameters, which will increase performance and efficiency [1], [2].

Every industry has some type of industrial process that needs to be adjusted for optimal functioning or normal operation. A variable speed drive (VSD) system is typically used to make these adjustments. They play a significant role in automation. They aid in process optimisation and lower investment, energy use, and cost of energy. VSD systems can be divided into three categories: mechanical drives, hydraulic drives, and electrical drives. The main subject of this chapter is electrical drives. Three fundamental elements make up the majority of electric VSD systems. The control system, power converter, and electric motor as shown in Figure 1. The load is connected to the electric motor either directly or indirectly (through gears).

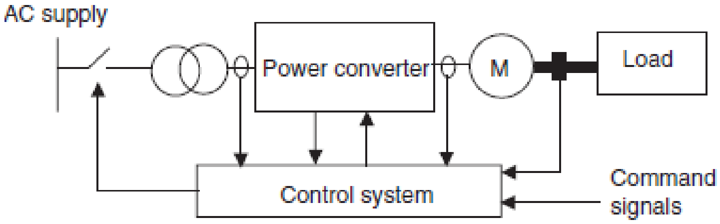

Figure 1: VSD schematic diagram.

Power semiconductor switches, which are a component of the power converter, are appropriately controlled by the power converter to regulate the flow of power from an AC source to the motor, frequently via a supply transformer. Electric variable speed drives are experiencing a revolution in applications such as computer peripheral drives, machine tools and robotic drives, test benches, fan pumps and compressors, paper mill drives, automation, traction and ship propulsion, cement mill and rolling mill drives thanks to recent advancements in power semiconductor and converter topologies.

The mechanical and electrical VSD system variables are necessary for control and protection in a suitable control system. Signals are typically produced by sensors, whose outputs are heavily influenced by the chosen control method and the desired functionality. Electric variable speed drives are introduced in this chapter, along with a brief rundown of their advantages. It investigates their categories from several angles. A brief description of their specification requirements to satisfy applications in various sectors is provided. It has been thoroughly investigated and compared between several VSD topologies. A few contemporary VSD applications are looked at and briefly discussed.

Advantages of VSD: According to the author, most industrial processes that use a motor can benefit from VSDs. How to put these advantages into numbers has frequently been a problem. Particularly for fan and pump drive applications, the energy savings potential of VSD may be clearly assessed.

Energy Saving: Savings are achieved by electric VSD in two ways: (a) directly by using less energy, and (b) indirectly by raising product quality. The latter is frequently more challenging to quantify. Only centrifugal loads, such as centrifugal fans and pumps, provide for direct energy savings. Such loads are frequently operated at set speeds. Pump fluid flow rates are often adjusted mechanically, usually with an automated valve. However, if a VSD is utilised, the motor speeds can be electronically adjusted to achieve the appropriate flow rate, which can save a lot of energy. The volume of flow is directly proportional to speed, pressure is directly proportional to speed squared, and input power is directly proportional to speed cube, according to the laws of affinity for centrifugal loads.

According to the affinity law, the power usage is inversely correlated with the motor speed. This suggests that if the speed is cut in half, the power consumption will be cut in half. As a result, energy savings happen as volume requirements drop. For instance, running a cooling system at 50% airflow volume only needs 12.5% of the electricity needed to run the system at 100% volume. There is a possibility for a large energy reduction at lower volumes because power requirements decline more quickly than the reduction in volume. Centrifugal fans and pumps are typically sized to manage peak volume demands, which typically happen for brief durations. As a result, centrifugal fans and pumps often run at low volumes. A damper can be opened or closed to regulate the airflow of fans. Even with a low throughput, limiting the airflow makes the motor work hard. Reduced fan speed provides the ability to lower energy usage when using a variable speed motor. The motor's speed can be changed to control the airflow. Monitoring factors like humidity, temperature, flow, etc. can help with control. The amount of energy saved increases with decreasing throughput requirements. According to estimates, the payback period for a 50kW fan or pump VSD equipment working 2000 hours per year is 1.23 years for 50% speed operation and 1.9 years for 75% speed operation. The VSD is estimated to cost £5.5k, and the price of electricity is £0.05/kW.

Improved Process Control: Operating systems are more productive when process control is improved with VSDs. The majority of industrial processes' throughput rates depend on a wide range of factors. For instance, throughput in continuous metal annealing is influenced by, among other things, the material's properties, the material's cross-sectional area, and the temperature of one or more heat zones. Conveyors on the line that are powered by constant speed motors must either run empty during the time needed for a heat zone's temperature to change, or they must produce scrap during this time. Both options squander resources or energy. However, with VSDs, the time required to change speed is far shorter than the time required to alter heat-zone temperature. A production line can run continuously by continuously changing the material flow to match the conditions in the heat zone. Less energy is used as a result, and less metal is scrapped [3], [4].

Reduced Mechanical Stress (Soft Starts): The mechanical system, including belts and chains, is under more stress when a motor is started using line power. An induction motor's direct on-line start-up is always accompanied by a large inrush current and poor power factor.VSD can enhance a system's operating conditions by providing a controlled, smooth start and by saving some energy while running. Although it is difficult to do more than estimate the cost-benefits of these, smoother start-up operation will increase life and decrease maintenance. The advantages of soft start, which are built into VSD, include the elimination of the uncontrolled inrush of current that happens when a stationary motor is connected to the full line voltage as well as the inescapable suddenly imposed high start-up torque. Benefits include reducing power loss caused by current inrush and extending the life of the motor and the driven machine through the use of mild, gradual torque.

Improved Electrical System Power Factors: Electric variable speed drives perform at close to unity power factor over the whole speed range when a diode supply bridge is used for rectification (the supply gives primarily actual power). When a completely controlled thyristor supply bridge is utilised (as in DC, Cyclo, and current source drives), the power factor starts at about 0.9 at full speed and gets progressively worse as speed decreases because of front-end thyristors (usually 0.45 at 50% speed and 0.2 at 25% speed). The three phase AC line voltage is converted to a fixed level DC voltage by modern pulse width modulated (PWM) drives. They carry out this action regardless of the inverter's output power and speed. Therefore, regardless of the power factor of the load machine and the controller installation design, such as by inserting a reactor or output filter between the VSD and the motor, the PWM inverters give a consistent power factor.

DISCUSSION

Disadvantages of VSD: Space, cooling, and capital expenses typically make up the cost of VSD.A few of the downsides are supply harmonics, motor derating, and acoustic noise. Fast switching devices on PWM voltage source inverter (VSI) drives introduce additional potential issues such premature motor insulation failures, bearing/earth current, and electromagnetic compatibility (EMC).

Acoustic Noise: In some setups, mounting a VSD on a motor raises the noise level of the motor. The drive's non-sinusoidal (current and voltage) waveforms cause vibration in the motor's laminations, which results in noise. The DC-to-AC inverter's transistor switching frequency and modulation are what cause the non-sinusoidal current and voltage waveforms produced by the VSD. The audible motor noise is dependent on the switching frequency, which may be constant or variable. In general, the output waveform is more resemblant of a pure sine wave the higher the carrier frequency. Full-spectrum switching (random switching frequency) is one technique for lowering audible motor noise. Full-spectrum switching is achieved by the VSD makers using an algorithm in the VSD controller. By analysing motor properties including motor current, voltage, and the desired output frequency, the performance of the motor is optimised. Despite being audible to humans, the resulting frequency range creates a family of tones that span a large frequency band. As a result, the motor noise is perceived as being much lower than it would be with a single switching frequency. There might not be a problem with motor noise. The positions of the motors and the volume of other equipment's noise are important considerations. Traditionally, the high frequency component of the motor voltage waveform is decreased by placing an LC filter between the VSD and the motor. Modern PWM inverter drives operate with very high switching frequencies and random switching frequencies, both of which lower noise levels. The magnetically generated noise that is emitted from inverter-fed induction motors has been addressed in a number of ways [5], [6].

Motor Heating: The majority of motor manufacturers create their products in accordance with NEMA specifications so they can run on electricity from the grid. The heating and cooling characteristics of motors are designed using power that is delivered at a constant voltage and frequency. Inverters with a high switching speed can create variable voltage and variable frequency with minimal to no noticeable harmonic content for many drive applications, especially those requiring relatively little power. These enable the use of ordinary or high efficiency induction motors with minimal or no motor derating. However, due to switching rate limitations in the inverters used in larger drives, their output voltages have significant harmonics of orders 5, 7, 11, 13, and so forth. These in turn result in harmonic currents, which further heat the stator and rotor windings (due to copper and iron losses). The leakage inductance is the major factor limiting these harmonic currents. The increased power losses, notably those in the rotor, may necessitate derating the motor by 10-15% for simple six-step inverters.

Constant speed drives currently in use frequently use an enormous induction motor. The original induction motor can typically be used to change these over to variable speed operation. The majority of the ensuing operation will be performed at a lower load and a smaller loss than what the motor was intended for. Lower-order harmonics in the voltage wave produced by modern PWM VSI drives are minimal. The wave is made up of pulses created by switching between the positive and negative sides of the DC link voltage supply at a reasonably high frequency. The rapid rate of change of the voltage supplied to the winding in larger motors that run on AC sources up to 6600V may lead to degradation and failure in the insulation on the entry turns of conventional motors. When using self-ventilated (fan-cooled) motors, lowering the motor shaft speed reduces the amount of cooling airflow that is available. Inadequate airflow arises from running a motor at maximum torque and low speed. As a result, the temperature of the motor insulation rises. This may be harmful and shorten the insulation's useful life or result in the failure of the motor. The addition of a cooling fan with a consistent speed and independent driving to the motor is one potential remedy. This strategy guarantees sufficient stator cooling over the whole speed range. However, because internal airflow is still a function of speed, the rotor will operate hotter than intended. Insulation failure is not a concern because the rotor lacks windings, although bearings may run hotter and need lubrication more frequently. Centrifugal loads create less of a challenge for fan-cooled motors. At slower speeds, pumps and fans, for instance, don't need the whole torque. Therefore, under these situations, motors have less thermal stress at lower speeds. Centrifugal load does not cause the motor to overheat above the insulating system's thermal limits.

Supply Harmonics:VSD, which is connected to the power distribution system as a non-linear load, causes current and voltage harmonics in the AC supply. If harmonic levels rise above a particular point, they could poison the power plant and cause issues. Transformers, cables, motors, generators, and capacitors linked to the same power source as the devices producing the harmonics may overheat as a result of harmonics. For harmonic control in electrical power systems, the IEEE 519 makes recommendations for best practises and specifications. The goal of such rules is to control both the overall total harmonic distortion of the system voltage provided by the utility and the overall harmonic injection from customers so that they do not result in voltage distortion levels that are unacceptable for normal system characteristics. The makers of VSD equipment use a variety of methods to decrease supply harmonics produced by VSDs with 6-pulse diode bridge rectifiers. The cost of these choices is expressed in Reference as a percentage of the cost of a fundamental system with a 6-pulse Diode Bridge. According to estimates, a drive with a line reactor will cost 120% more than one without for low power VSDs. A double wound transformer's VSD is 210% while a 12-pulse diode bridge's VSD is 200% with a polygon transformer. The active front-end solution, which is predicted to cost 250% more, is the most expensive. Order harmonics are produced for the 6-pulse converter n6p1 (5, 7, 11, 13, 17, 19, etc.). Recommendations about the allowable harmonic limits are set forth by IEEE 519 in order to minimise the effects on the supply network. Therefore, either harmonic filtering or the use of a greater converter pulse number is required for higher driving powers. In general, using a greater pulse number is the more affordable option.

Drives Requirements & Specifications: High reliability, low initial and operating costs, high efficiency across the speed range, compactness, satisfactory steady-state and dynamic performance, compliance with relevant national and international standards (e.g., EMC, shock, and vibration), durability, high availability, and ease of maintenance and repairs are some of the most typical requirements for VSDs. Depending on the application and the sector, the ranking and priority of these needs may change. For low performance drives, such as fans and pumps, the initial cost and efficiency are crucial because energy savings are the primary benefit of using variable speed drives. However, due to a lack of available space, other industries, including the marine sector, place a higher importance on the equipment's compactness (high volumetric power densities). Since water is readily available and forced water-cooling produces a more compact drive solution, direct raw water-cooling is the method of choice in these conditions. Reliability, availability, and physical size are particularly important criteria in crucial VSD applications, including military marine propulsion. Cost is comparatively less important. But meeting these demands raises the price of the fundamental drive unit.

The VSD equipment can function even when a component fails because to component redundancy in series and parallel. These are often fixed as part of routine maintenance.Drive failures could cost many times as much as the drive itself in other crucial applications (such hot mill strips or subsea drives). For instance, it can be exceedingly challenging to reach a drive down on the seabed that is several kilometres below sea level. This section lists the VSD specifications for numerous driving applications across several industries.

The Mining Industry:DC Drives make up the majority of older large mine-winders. Cyclo-converters with AC motors are typically used in new construction and retrofits. Small mine winders (below 1MW) typically stay DC, though. The primary prerequisites are:

High availability and dependability.

a) Full regeneration.
b) Few applications needing single quadrant operation.
c) Wide speed range
d) Low torque ripple.
e) Low supply harmonics.
f) Low audible noise emissions.
g) High beginning torque required.
h) High torque required constantly during slow speed running.
i) Flameproof packaging.

The Marine Industry:the initial purchase price is one of the prerequisites for this sector.

a) Reliability,
b) Ease of maintenance,
c) Low component count, and
d) Straightforward design
e) Transformer less,
f) Water-cooled VSD equipment is always preferable,

As are the size and weight of the apparatus other elements that would be desirable include:

1) A requirement for the integration of Power Management functions
2) High volumetric power density (smallest size possible)
3) Remote diagnosis, which enables fault-finding by specialists on-site in urgent circumstances.

Thrusters typically have driven powers between 0.75 and 5.8 MW, and propulsion typically has driven powers between 6 and 24 MW. Powers between 1 and 10MW for propulsion are the direction of change in the commercial market. For uses in the navy, more powers are needed.

The efficiency of the package drive must be at least 96%. When employing PWM inverters, issues with harmonics and noise must be taken into account. A filter must be able to handle the supply side harmonics that are generated. Given current technology, power converters with a MW rating greater than 1 generally have a 12-pulse supply bridge. A diode supply bridge works well since two-quadrant operation is generally necessary. Use of the dynamic brake chopper is occasionally required for crash stops. DC Bus - can be advantageous for supplying wharf loading equipment, however the driving power ranges are such that commercially available solutions already suffice for this purpose. Standard AC equipment should be used, but if inverter-compatible motors turn out to be less expensive, that may be the choice. Acoustic and electromagnetic emission with less noise is crucial. No high torque at low speed is necessary. In order to prevent the requirement for extra Programmable Logic Control (PLC), programming and increased input and output capabilities are necessary.

The Process Industries: Initial purchase price (long-term cost of ownership typically has little bearing on purchasing decisions) and efficiency in continuous processes are the primary criteria of this market.

a. Dependability;
b. Ease of upkeep
c. Avoid the facility

The preferred option in the industry is air-cooled drives. Drives with air cooling are thought to be less expensive than those with water cooling. Customers are frequently concerned about leaks because they think that water and electricity don't mix well. The offshore sector is an exception, where water-cooling is required since equipment size is crucial. In most process plants, there isn't a generally accepted need to save space. Customers frequently request ease of maintenance and robust diagnostic capabilities as desirable qualities.

The market needs cost-effective stand-alone drives with a range of power levels from a few microwatts to 30 megawatts. Standard AC equipment should be used. However, if non-standard, but easier & less expensive machinery can be provided, a benefit could be obtained.

a. Fan, pump, and compressor two-quadrant operation
b. Operation in four quadrants for various Test Benches
c. The control must support extra features like flow and pressure management, temperature protection, and motor bearing temperature, among others.
d. In general, there is no demand for field weakening.
e. A harmonic filter shouldn't be necessary to reduce the harmonics the drive imposes on the power system.

Harmonics need to be reduced The PWM VSI now holds a dominant position in the Low Voltage (LV) market. There are several effective driving options in the Medium Voltage (MV) market, including cyclo-converters and load commutated inverters (LCIs). But the market for MV PWM VSI drivers is expanding [7], [8].

The Metal Industries: Low maintenance costs have been a major driver in the switch from DC to AC. The requirements of this industry are:

a. Reliability - high availability
b. Efficiency of the equipment - long-term costs of ownership
c. Power supply system distortion - more onerous regulations from the supply authorities
d. Initial purchase cost - very competitive market, and large drive costs have a big impact on total project costs
e. Belief in the provider and their offering

The following is a list of appealing characteristics:

1. System discs that can be programmed using robust programming languages Strong maintenance and diagnostic tools; low EMC noise signature; ability to connect to an existing automation system via a network, Fieldbus, or serial link; preference for air-cooled stacks; water-cooled stacks are acceptable if a water-to-air heat exchanger is

used; preference for air-cooled stacks; physical size of equipment is frequently not a major factor.

2. Fire prevention systems are essential for driving machinery EMC rules, increased voltage levels' effects on motor insulation, and the in acceptability of cooling with "dirty" mill water are the three primary market problems. Deionized water circuit maintenance is a major problem.

CONCLUSION

Drives are crucial elements in systems for industrial automation and control. The proper drive must meet the demands of the application, including those for speed, torque, and precision. While DC drives are appropriate for applications demanding great torque at low speeds, AC drives are suitable for applications requiring speed control. Stepper drives are utilised in applications demanding accurate positioning, whereas servo drives are used in applications needing great accuracy and precision. It is crucial to take into account aspects like power rating, voltage and current ratings, and control mechanisms when choosing a drive. Engineers and technicians may choose the best drive for their applications by being aware of the many drive types and their parameters, which will increase performance and efficiency.

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CHAPTER 25

DRIVE CLASSIFICATIONS AND CHARACTERISTICS

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ABSTRACT:

Classifications for drives are a crucial component of computer storage systems. They assist in classifying and maintaining data storage devices according to their capacities, speeds, and connection types. The various drive classes and their features are outlined in this chapter. The benefits and drawbacks of each drive classification and their uses in diverse contexts are also covered in the chapter.

KEYWORDS:

Energy Recovery, Induction Motor Drive, Power Factor, Speed Range, VSD.

INTRODUCTION

Drive Specifications: An improper specification of an electric VSD may lead to a disagreement between the end user and the equipment's supplier. Frequently, the price is a postponed project's completion and/or loss of income. Requirement specifications should take into account the operating and environmental circumstances in order to prevent this issue. From the start of the project until the project is completed successfully with commissioning and handover, the equipment provider and the customer must collaborate and work as partners. It is advised that the end user purchase the entire drive system from a reputable source, including system engineering, commissioning, and engineering support. Finding relevant national and international standards for EMC, harmonics, safety, noise, smoke emissions during faults, dust, and vibration is one of the top priorities. Over-specifying the needs could frequently lead to a too expensive solution. Poor performance and dissatisfaction stem from not outlining the requirements enough. The AC input voltage, shaft mechanical power, and shaft speed are the driving interfaces that the end user needs to select. These are used to calculate the torque and current. The choice of motor affects frequency and power factor. A "harmonic survey" is always advised before using a high-power drive. Such a survey will demonstrate the current harmonic level and quantify how the new drive will affect the harmonic levels [1].

Drive Classifications and Characteristics:

Classification by Applications: Under this classification there are four main groups:

a) Appliances (white goods)
b) General purpose drives
c) System drives
d) Servo drives

Classification by Type of Power Device: The oldest and currently the most popular controllable solid-state power device for MV - AC voltages between 2.4 kV and 11 kV - high power drive applications is the Silicon Controlled Rectifier (SCR), commonly known as the

Thyristor. Even though these devices can operate at high voltages and currents, their maximum switching frequency is constrained, necessitating the use of a challenging commutation circuit for VSI driving. Due to this, SCRs are most frequently used in devices like cyclo-converters and LCI current source converters, which allow for natural commutation. With the help of the Gate Turn-Off Thyristor (GTO), PWM VSI drives are now practical for LV drive applications. One of the first sectors to gain significantly from such a device was the traction business. This device could only be used in high performance applications where SCR-based drives were unable to deliver the necessary performance due to complex gate drive, constrained switching performance, and the requirement for a snubber circuit. The IGBT, which combines the qualities of both devices—the current handling capacity of the bipolar transistor and the ease of driving of the MOSFET—has significantly surpassed the popularity of bipolar/MOSFET type transistors in the latter part of the 1980s. With ratings up to 3MW, traction inverters are made for DC links with voltages between 650V DC and 3 kV DC. While the most recent generation of traction inverter equipment is nearly entirely IGBT-based, the previous generation was GTO-based. The cost, weight, and volume of the equipment have all been reduced by 30% to 50% as a result of the switch to IGBT. Because of its high cost, snubber needs, and associated snubber energy loss, which is proportional to the square of the supply voltage, early attempts to employ GTOs in MV applications failed. Energy recovery circuitry makes it possible to recover the majority of the snubber energy, but also increases the converter's cost and complexity. With the development of high voltage IGBT and IGCT, MV PWM VSI with supply voltages up to 6.6 kV and power ratings more than 19MW are now commercially accessible.

Classification by the Type of Converter: The output voltage magnitude and frequency of the power converter can be adjusted. However, by utilising the proper switching function, such as PWM, these two functionalities are frequently merged into a single converter in applications. The rotational speed of the magnetic field in the machine's air gap and, consequently, the output speed of the mechanical drive shaft, can be changed in AC machines by appropriately adjusting the stator frequency. Under normal operation, the machine's magnetic flux density must be maintained constant, and likewise, the ratio of the motor voltage to the stator frequency must be maintained. Most VSD systems get their input power from sources that have a constant frequency, like the AC supply grid or an AC generator. An AC/AC converter is required to produce energy with a changeable frequency. Some converters, such as cyclo-converters and matrix-converters, convert power directly from AC/AC without using an intermediary step. DC links are necessary for other converters (as current sources or voltage sources). By simply altering the inverter's phase rotation while driving the switches in the proper order, the direction of the shaft rotation can be changed in all AC variable speed drives.

DC Static Converter: This drive uses the most straightforward static converter. It has a wide speed range and is simply setup to be a regenerative drive. High torque with exceptional dynamic performance is provided over the whole speed range. Regrettably, the motor needs routine maintenance, and the top speed frequently poses a constraint. The highest power that can be used is constrained by the commutator voltage, which is around 1000V. The motor's commutator severely restricts the continuous stall-torque rating.

Direct AC/AC Converters (Cyclo-Converter): For a regenerative converter, a typical cyclo-converter consists of three antiparallel 6-pulse bridges that can function with natural commutation in any of the four quadrants. High performance, high power >2MW drives with a maximum motor frequency of less than 33% of the mains frequency are best suited for this kind of drive.

Matrix-converter: The force-commutated cyclo-converter, also known as a matrix-converter, may represent the most recent state of the art because it allows for good input and output current waveforms, eliminates the DC link components, and has minimal input-to-output frequency ratio restrictions. The development of this kind of converter is still in its infancy. The ability of this drive to convert AC fixed frequency supply input to AC output without a DC bus is by far its greatest benefit. For integrated motor drives with relatively modest power ratings, it is perfect. Bi-directional switches' greater silicon usage, the fact that their output voltage is always lower than their input voltage, and the complexity of their commutation and protection systems are some of its major downsides. Direct AC/AC power conversion is offered by matrix converters without the use of an intermediary DC link and its associated reactive parts. As listed below, they have important advantages for integrated drives. Matrix converters have not been commercially exploited because of voltage ratio limitation, device count, difficulties with current commutation control, and difficulties with circuit protection. They have a reduced volume due to the absence of DC link components. They can operate at the higher thermal limit imposed by the power devices. They have a reduced harmonic input current compared to Diode Bridge [2], [3].

Current Source Inverter (CSI): The rectangular blocks of current from the motor bridge that come from a supply converter, whose output is maintained at a constant current by a DC link reactor and current servo, are the output of this inverter. Fast thyristors are often the foundation of this kind of inverter.

Load Commutated Inverter (LCI): Thyristor natural commutations are often accomplished with synchronous machines at rates greater than 10%. The presence of the motor's electromotive force (EMF) induces natural commutation, which is known as load commutation and gives the drive its alternate name of LCI. Low speeds prevent motor bridge commutations because the motor voltage is too low. The supply converter is used to do this. LCI drives for induction motors can be produced by connecting a large capacitor to the motor terminals. The LCI drive has a higher speed range (up to 10,000 rpm) and a 100MW maximum power rating. It has a moderate dynamic performance and delivers full load torque over the whole speed range. The popularity of these drives has grown thanks to their straightforward converter architecture and maintenance-free motor designs (both synchronous and induction). For high power drives (such as conveyors, pumps, fans, compressors, and marine propulsion), it is still a well-liked option. At slow speeds, the LCI drive's performance is constrained. Additionally, it experiences torque pulsation at 6 and 12 times the frequency and beat frequencies of the motor. Mechanical resonance can be triggered at certain speeds. With speed, its AC power factor changes. If necessary, 12-pulse systems can lessen the frequency of the torque pulsations.

Forced Commutated Inverter (FCI): Another workable option is to pair externally commutated current source converters with an induction motor. A bank of capacitors is typically employed at the motor terminals to account for the inductive component of the motor current. The relationship between the capacitor current and the motor voltage and frequency is linear. Fast-loading commutation requires a high enough compensating current. Forced commutation when the capacitive current is too low for compensation and the speed is lower.

It is possible to force commutation using a variety of methods. The one in the image above is based on a DC link diverter and includes a GTO, loading components in parallel, and a diverting/compensating capacitor. Devices that force commutation, including reverse blocking GTOs and IGCTs, are used in modern drives.

Slip Power Recovery (Kramer):A slip-ring wound-rotor induction motor's rotor current is rectified, and the power is then converted back to AC at a set frequency and delivered into the supply network. For conventional systems, a diode bridge is used to rectify the low frequency slip ring currents before inverting the DC power into mains frequency AC power. Traditional designs exhibited strong torque pulsation, low levels of low frequency AC supply harmonics, and poor AC mains dip immunity. The Rotor Drive, the most recent iteration of this sort of drive, uses PWM-VSI inverters for the rotor and AC supply bridges. The drive has numerous benefits over conventional circuits, including maintaining sine wave currents in the AC rotor circuits and: Low AC harmonics, little torque pulsation, great resilience to AC supply dips, and very cost-effective if only a small speed range is needed, but still needs a separate starter, Ability to operate at rated speed without the use of electrical circuits If the speed ability is used to provide a speed range, the converter cost is lowered by 2:1.

DISCUSSION

PWM-VSI Converter: Drives with voltage-fed PWM converters on induction are currently more popular due to the availability of power electronic switches with turn-off capabilities, such as FETs, BJTs, IGBTs, and GTOs. Among all variable speed drives, the PWMVSI drives give the maximum performance. The usage of micro-controllers and recent advancements in switching technology have significantly improved this sort of drive. The inverters can now work in a speed range that is unlimited. The supply power factor is consistently close to unity. If more hardware is needed to regenerate power back into the mains supply, it can be done with ease. The switching frequency and motor ripple current are connected, and in big drives, the motor may derate by less than 3%.

Thermal Cycling: The driving duty cycle has an impact on power equipment' dependability and lifespan as well. Power devices are subjected to increased thermal strains as a result of repetitive load cycle duty. Drives that often accelerate and decelerate cause recurrent junction temperatures to rise and fall during cycle duty. The maximum permitted number of cycles for a specific rise in the junction temperature of a power device is frequently used to estimate the lifespan of a device. Even though this is true for all kinds of power devices, IGBTs, which utilise wire bonds and solder layers, have a greater need for this. The maximum junction temperature rise of the IGBTs is constrained in contemporary IGBT-based converter designs to a level that ensures a conservative number of thermal cycles over the drive's lifespan. For repetitive cycle duty (such as in a steel mill) and non-repetitive cyclic duty (such as in fan pumps), the typical junction temperature rise is 30 °C and 40 °C, respectively [4]–[6].

Variable Speed Drive Topologies:

DC Motor Drives: With very few exceptions, the DC motor drive was until recently the most widely used and least priced type of electric variable speed drive. Given that the currents flowing through the rotor armature coils are AC and those flowing through the brush are DC, the mechanical commutator is an electromechanical device that converts power in both directions from DC to AC. The development of the more reliable, less expensive squirrel cage induction motor drive has caused a relative drop in the popularity of the extensively used, well-known DC drive. Unfortunately, the mechanical commutator has major commutation current and speed constraints, which restricts the power per unit to 1-2 MW at 1000 rpm and may not be accepted at all in chemically hostile or explosion-prone settings, despite the fact that it is not awful in terms of losses and power density. Because there are so few flameproof DC machines available, the DC drive has only been used in dangerous environments. In these conditions, commutator and brush maintenance is challenging. Furthermore, at full load output, continual sparking at the brushes is all but guaranteed.

By adjusting the applied armature voltage, DC drives became popular in early electric drive applications due to the individually excited DC machine's inherent simplicity in speed control. Phase-controlled rectification can easily produce this variable armature voltage, and it has now largely supplanted the Ward-Leonard systems that were previously in use. Positive and negative DC voltage as well as DC current output are both available as four-quadrant operations of the variable DC voltage provided by the AC/DC converter. Brushed permanent magnet motors have been utilised for a while in many different applications, especially non-regenerative drive applications.

Motor speed and output torque are roughly inversely correlated with converter output voltage and armature current, respectively. Therefore, speed control with an accuracy of about 5% is possible using armature voltage sensing. The DC drive power factor is proportional to motor speed as long as the motor excitation is maintained constant. Constant excitation systems are employed because most pumps, compressors, and fans require a torque proportionate to the square of speed; thus, the aforementioned connection holds true. At maximum rated speed, a DC drive's normal power factor is 0.85. Numerous additional kinds of electric drives can be governed by this relationship.

Regeneration to the mains supply is accomplished by either reversing the motor field or armature connection if a sluggish dynamic response is satisfactory. An alternative method of regeneration that produces a quicker reaction is to link a second Thyristor Bridge in the opposite direction of the primary bridge. With a transition period of 15 ms between full torque motoring and full torque regenerating in this situation, quick responsiveness is achievable. For powers up to 1MW, the 6-pulse drive design is suitable. This restriction results from the converter's generated AC line current harmonics rather than any limitations in semiconductor devices. A Thyristor or transistor solid-state switch employs variable mark-space control as the basis for a force-commutated or "chopper" converter for DC motors. With a diode frontend converter, a fixed, smoother DC supply is obtained from the mains by uncontrolled rectification and swiftly applied, removed, and reapplied to the apparatus for programmable periods, resulting in the application of a varied mean DC voltage to the DC motor (see Figure 1).

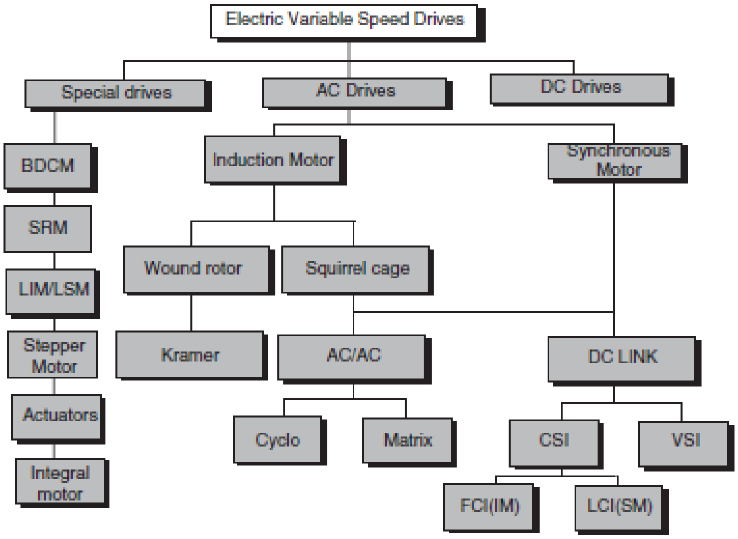

Figure 1: Classification of electric VSD.

Induction Motor Drive:

Squirrel Cage Induction Motor: The VSD industry uses squirrel cage induction motors the most frequently because they have a simpler structure than DC motors. They are dependable and strong. They are inexpensive to maintain and are offered at costs that are quite favourable. They can be built with completely enclosed motors to function in hazardous conditions. Their starting cost is far lower than that of commutator motors, and they have an equivalent level of efficiency. They are appealing for use in industrial drives because of all these advantages. The three-stator windings provide a synchronously spinning magnetic flux. The motor pole count and supply frequency affect this speed: Circulating current is produced when the revolving flux intersects the rotor windings and induces an EMF there. When the stator flux interacts with the second magnetic flux created by the rotor currents, torque is created to speed up the machine. The induced rotor voltage decreases in amplitude and frequency as the rotor speeds up until an equilibrium speed is attained. The torque required by the load can now be produced by the induced rotor current. The slip frequency, which is typically 3%, causes the rotor speed to be slightly slower than the synchronous speed.

The ratio of stator voltage to frequency must be maintained roughly constant to provide consistent excitation of the machine and to maximise torque production up to the base speed.

There are three separate operating areas for induction motor drives:

(a) Constant Torque: The supply voltage sets a maximum value that the inverter voltage can reach.

The rated flux linkage is maintained up to the base speed as the motor speed and voltage increase in proportion, constant V/F. At speeds up to around this base value, torque values up to the maximum value can be generated. The flux linkage's square is proportional to the maximum torque that can be applied. The induction motor is often built to deliver a continuous torque rating of between 40 and 50 percent of its maximum torque.

(b) Constant Power: The inverter's frequency can be increased for higher speed, but the supply voltage must be maintained constant at the highest amount permitted by the supply. As a result, the stator flux linkage falls off in an inverse relationship to frequency. Up to the speed when the motor's peak torque is just enough to meet the constant power curve, constant power can be achieved. Typically, a continuous power speed range of 2 to 2.5 is possible.

The motor frequency rises within this range until it reaches its maximum speed.

(c) Machine Limit (Pull-out Torque): When the machine limit is attained, the torque decreases proportionately to the square of the motor frequency. As the motor power factor declines, operation at the higher end of this speed range may not be possible. This leads to a stator current that is more than the rated amount. If the duty factor is not low, significant motor heating may occur.

Applications needing quick and accurate control of torque, speed, and shaft position use induction motors. A transient response at least equivalent to that of a commutator motor can be accomplished using the commonly utilised control technology known as vector control. The voltage, current, and flux linkage variables in this circuit are space vectors, and by projecting the space vector on three radial axes spaced 120 apart from one another, one may determine the instantaneous values of the phase quantities. The real and imaginary parts of the space vectors are divided, resulting in distinct circuits with equal parameters in the direct and quadrature directions. Due to the induction motor's enormous magnetising inductance, changes in the rotor flux linkage can be forced to happen only very slowly. To maintain a constant rotor flux linkage, vector control relies on maintaining a constant instantaneous magnetising current space vector magnitude. The space vector, which is controlled to have constant magnitude to maintain constant rotor flux linkage, is combined with a set of immediately controlled phase currents to power the motor. A space vector that is in space quadrature with the instantaneous magnetising current space vector makes up the second component. Instantaneous control is used to instantly adjust this component so that it relates to the demand torque. The motor is able to react instantly to a demand for torque to the degree that the inverter can provide instantaneous stator currents fulfilling these two specifications. This characteristic, along with the induction motor's rotor's comparatively low inertia, makes this drive appealing for high-performance control systems. A method for monitoring or calculating the immediate magnitude and angle of the rotor flux linkage's space vector is necessary for vector control. In general, direct measuring is not practical. The development of control setups that estimate measured electrical terminal values is advancing quickly.

Slip-ring (Wound-rotor) Induction Motor Drive: Induction motors with wound rotors and three rotor slip rings have been utilised in variable speed drives for a long time. The power crossing the air gap in an induction motor divided by the synchronous mechanical speed is the torque. Early slip-ring induction motor drives involved the passage of power via the motor and into external resistances that were linked to the rotor's slip ring terminals. As a result, the drive was inefficient over the majority of speed ranges. Modern slip ring drives recuperate power from the rotor circuit and feed it back to the supply system using an inverter.

The following methods can be used to regulate the speed of a slip-ring induction motor:

a) Stator frequency control, similar to that of a cage rotor machine;
b) Rotor frequency control;
c) Rotor resistance control; and
d) Slip energy recovery (Kramer system).

The latter two are frequently employed due to capital cost concerns. It is commonly known that rotor resistance can be added, particularly when starting big induction motors. Rotor resistance addition mostly affects the speed at which maximum motor torque is generated. Earlier methods to address this problem were to convert the rotor power to DC and feed a DC motor on the same shaft, however this method suffers from power dissipation as heat in the rotor resistance bank. Therefore, when operating at a lower speed, the rotor slip energy is transformed back into mechanical power. The "Kramer" system is this. The additional maintenance and capital costs of this strategy were a drawback. By switching out the DC machine for a line-commutated inverter that sends the slip-energy back to the AC line either directly (on lower power systems) or via a transformer, the static Kramer system solves these drawbacks. The slip energy recovery apparatus (DC machines or static inverters) only needs to be rated for a small portion of the maximum motor rating thanks to the Kramer drive system.

This is accurate when a narrow speed range is needed, as long as a distinct method of starting the motor is offered. This is due to the fact that the rotor voltage is inversely related to speed and the rotor current is proportional to torque.

Naturally, a controlled speed range of zero to maximum might be accomplished if the slip energy recovery network can be rated to resist full rotor voltage (produced at stationary).

But in most cases, this is only possible with smaller motors (around 2000kW), where the rotor voltage is low enough to support an affordable inverter package. The slip energy recovery network must be rated at full motor power if a whole speed range is required, making static Kramer drives uneconomical for large speed ranges. For a system with a wide speed range, the overall system power factor would be extremely low.

For the aforementioned reasons, Kramer drives are ideal for high power drives (>200kW) that need a narrow speed range. Therefore, pump and fan drives present good commercial applications. Induction generator torque is controlled by the recovery mechanism when employing Kramer drives for low speed endurance dynos. Current harmonics are generated, as with other line-commutated converters and inverters, however they can be lowered to tolerable levels.

The magnitudes of the harmonic currents generated are proportionally less with drives where the solid-state converters must handle the entire drive power, as the slip-energy recovery network is only power rated in direct proportion to the speed reduction required (assuming constant load torque). Rotor rectifiers' harmonics are transferred through the rotor and manifest themselves in the main supply as non-integer harmonics. The slip-ring induction motor drive's main drawbacks are (a) the higher cost of the motor in comparison to a squirrel cage, (b) the requirement for slip ring maintenance, (c) the challenge of using the drive in hazardous environments, (d) the requirement for switchable start-up resistors, and (e) the drive's subpar power factor in comparison to other drive types.

Synchronous Motor Drives: Let's say that the induction motor were to rotate at the synchronous speed by an external means in order to better grasp how the synchronous machine functions. The rotor currents' frequency and magnitude would both be 0 in this scenario. The rotor would polarise similarly to a permanent magnet if an external DC power source were linked to the winding. The stator's magnetic field would rotate in the air gap, and the load angle would cause the rotor to lag behind the stator by a little constant angle. As long as the DC supply is kept to the rotor field winding, the load angle is proportionate to the torque delivered to the shaft, and the rotor remains revolving at synchronous speed. The synchronous motor differs greatly from the induction motor in that the magnetic flux generated by the rotor winding intersects the stator windings and creates a back EMF. The requirement is to maintain the ratio V/F constant, which means varying the applied voltages and stator frequency in accordance to the desired motor speed.

Phase adjustment of the supply bridge converter produces a variable DC current in the DC link choke. The Inverter Bridge switches this current into the motor stator windings at the proper phase position with respect to the rotor angular position as determined by the position sensor in order to maximise the torque from the synchronous motor. The back EMF produced by the synchronous motor is enough to commutate the current into the next arm of the inverter bridge when it is operating at speeds greater than roughly 10%. Therefore, because this kind of inverter is machine (motor) commutated, its configuration is just like a regular DC drive. Thus, force-commutated circuitry's complexity, cost, and restricted power capacity are avoided.

At low speeds, the motor's back EMF is inadequate to drive a thyristor. Therefore, the strategy is to quickly phase back the supply converter bridge to lower the DC link current to zero and then, after a little time (to make sure all thyristors in the machine bridge are turned off), to reapply DC current once the proper Thyristor trigger pattern has been restored. Changeover to continuous DC link current operation takes place as motor speed and back EMF rise to a level necessary for machine commutation.

The rotor position sensor, located on the motor shaft, whose angular position is measured by optical or magnetic probes, determines the proper Inverter Bridge firing instant during the starting mode. Sensing of stator voltage is employed in machine commutated mode. Angular rotor position sensing is required for the low speed or pulsed mode to produce the most torque. However, the inverter system can be configured to produce a low fixed frequency in the pulsed mode if less than full load torque availability at low speed can be accepted. Then, as motor rotation is recognised (either incrementally or at a predetermined ramp rate), this frequency is raised until enough back EMF is produced to enable switching to the voltage-sensing mode.

All Thyristor devices are line or machine commutated, which is the main benefit of this kind of drive, as was previously mentioned. It is avoided to use expensive and intricate forced commutation circuitry, and quick turn-off thyristors are not required. This means that inverter systems of this kind can be created at very high powers, up to 100MW. Additionally, because force commutation is avoided, converter efficiency is good.

The machine Inverter Bridge's thyristors must be activated at a specific angle to allow enough time for commutation from one device to the next. The synchronous motor as a result operates at a high leading power factor of about 0.85. However, the overall drive has the properties of a DC drive, where power factor is proportional to speed, as far as the mains supply is concerned.

The fact that this kind of drive is naturally regenerative and reversible is another crucial feature. The Inverter Bridge is triggered in the fully advanced position for regenerative operation, turning it into a simple diode bridge in practise. As a result, the DC side of the supply Converter Bridge produces a DC output voltage that is roughly proportionate to motor speed. This converter bridge is currently activated in the regenerative mode, replenishing the supply system with electricity. The Inverter Bridge's thyristors are actuated in a different order to achieve reversing operation.

Because it includes an effective brushless motor and a very straightforward and efficient converter, this type of drive is frequently used throughout a wide power range. Permanent magnet synchronous motors are more prevalent at lower powers, say below 30kW. The synchronous type requires two different types of converters, in contrast to the induction motor. First for primary power conversion, second for field excitation at low power. The rotor exciter is fed by the field converter by slip rings, brushes, or a brushless exciter if desired. In high power applications, a coordinated control of the two converters allows for effective wide-speed range management as well as active and reactive power control. Synchronous motors are favoured for high power applications due to their capacity to regulate reactive power flow through suitable excitation regulation. Synchronous motors typically offer greater efficiency and a wider speed range. The cost of synchronous motors is often higher than that of induction motors. Synchronous motors can be driven for the same inverter with vector control techniques using new high power PWM-VSI drives.

Stepper Motors: Similar to BDCM, stepper motors can either have a rotor with permanent magnets implanted in it or bonded to it, or they can have a rotor without any magnets. The latter type is made of a ferrite magnetic substance and has grooves carved onto its circumference that run lengthwise to the rotor axis to create teeth. Magnetic reluctance (as in SRM) or magnetic attraction (b as in BDCM) or a combination of the two can be used to produce torque. The primary operation of stepper drives is to accelerate at full torque to reach maximum speed, maintain the speed, and decelerate at full torque. Stepper drives do not provide dynamic speed control. The permanent magnet type stepper motor offers more torque at a given speed than the reluctance type, especially at start and low speeds. The majority of drives have controllers that connect to a communications link for supervisory control by PLC, hardwire connectors for analog/digital inputs and outputs, and others are set up with software for communications with a computer or portable keypad [7]–[9].

CONCLUSION

Drive categories are essential for managing and organising computer storage systems. Hard disc drives (HDDs), solid-state drives (SSDs), and external drives are only a few types of drives. Each classification has an own set of traits, benefits, and drawbacks. While SSDs have higher read and write speeds and are better suited for high-performance applications, HDDs are good for storing massive volumes of data. The portability and convenience of external drives make them perfect for content sharing and backup. The user's unique wants and requirements must be taken into account while selecting the appropriate drive classification.

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